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FLOOD MITIGATION OF A CALCULATION RAIN WITH A 1% PROBABILITY OF OCCURRENCE FOR WETLANDS AND PEATLANDS FROM NORTH-WEST REGION OF ROMANIA - CASE STUDIES

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Abstract. The paper's goal is the modeling of some flood events as a response to a calculation of rain with a 1% probability of occurrence for several characteristic (case studies) wetlands (WL) within the Northwest Region of Romania (NWPEAT project). The aim is to find the reaction and their efficiency in mitigating the maximum torrential runoff produced in the high mountain area (runoff formation area) or on its periphery (water outlet area under the effect of the hydraulic features of the terrain slope). The methodology was applied to representative case studies, which reveal different/diversified conditions, both from the climatic, morphological, pedological, land cover, hydrological, etc. points of view. The modeling process was preceded by the inventory of the work sites, their spatial analysis by morphological units and within the water balance, and the analysis of runoff and aridity coefficient. In the same direction, an important step was the study of the watershed shape of the swamps or peatlands, making a choice, especially towards developed in-width or quasi-circular watersheds. The two scenarios, applied in the case of each effective WL, also assumed the consideration of their surface in two variants: a natural, effective variant, occupied by the current ecosystem, and a second variant where the nature of its surface is considered identical (petrography, soil, cover, etc.) with that of the slope (so the WL ecosystem is missing). The result is more than conclusive, the current surface with ecosystem layer is bringing a two-fold reduction of the maximum effluent flow, compared to the second variant. The same thing is also seen in the case of the event modeling on the watershed, with the same two conditions of the WL surface. Thus, the study (the first of its kind at the national level) once again confirms the extremely important effect of WL on torrential runoff, encouraging the massive rehabilitation and protection of this type of surface in runoff formation.
Keywords: peatland, northwestern Romania, water balance, hydraulic modeling, hydrograph, flood mitigation.

1. INTRODUCTION
1.1 General remarks

Swamps and peatlands are dynamic ecosystems in which environmental factors are influencing both their structure and their functions. According to various authors, peatlands cover an area of about 400 million hectares in 180 countries, equivalent to 3% of the total continental or island surface (Joosten and Clarke, 2002; IBB, 2017).

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The role of wetlands, concerning the natural and anthropogenic environment, consists of several ecosystem services, like ensuring a suitable living environment for specific flora and fauna communities, flood mitigating by storing significant amounts of water and releasing them gradually, filtering water and improving its quality, etc. (Mitch and Gosselink, 2000; Obropta et al., 2008; Bătinaș et al., 2016; Dunea et al., 2020; Dunea et al., 2021; Sabău et al., 2023).

Since ancient times, the peat resource found in some wetland areas has been exploited for local and domestic purposes, their degree of damage being, in general, reduced. In the last two centuries, to the rudimentary exploitation activity, drainage and desiccation activities were added, because of the human habitats' development or industrial sites extension (the case of the municipality of Miercurea Ciuc, etc.), the expansion of agricultural areas and pastures, etc. These activities were often followed by the destruction of specific wetland habitats (Clarke and Reiely, 2010; Evers et al., 2017; IBB, 2017).

Wetlands situated in the vicinity of urban and peri-urban communities can become real recreation centers on one hand, and on the other hand, to be transformed into real organic or inorganic waste deposits resulting from human activities (Ehrenfeld et al., 2003).

Due to the expansion and development of the human element and its activities, the functions of European peatland ecosystems are so affected that half of them no longer accumulate peat, while a fifth of the secular peatlands have disappeared (Joosten and Clarke, 2002; IBB, 2017). Considering the rate of formation of the 20-60 cm peat layer within 1000 years, the vulnerability and threat to which they are subjected becomes obvious (Couwenberg and Joosten, 2005; IBB, 2017).

As previously mentioned, the functions of peatlands are complex and influence several indicators of the terrestrial system (biodiversity maintenance, carbon and water reserve, natural regulation of water levels and rivers' discharges, etc.) (Obropta et al., 2008). The layers of peat, slowly accumulated over thousands of years, are a real museum of natural history, offering valuable information on the dynamics of the fauna and especially the vegetation over time. They are true reservoirs of biodiversity, considering the many relict species housed, and kept within an acidic water environment (IBB, 2017; Ahmad et al., 2020; Biagi et al., 2021; Kizuka et al., 2023).

Within the current delicate climate context, their role can be a major one in moderating climate change, as peatlands store approximately half of the soil's carbon stock through their ability to absorb and store for long-term periods, the atmospheric carbon dioxide. The drainage of peatlands, followed by the release of carbon dioxide and methane gas, can have a significant impact on the increase in global temperature and the intensification of climate change events (Obropta et al., 2008; IBB, 2017; Koivunen al., 2023; Pettit et al., 2023).

According to various studies, in the last 10,000 years, the atmospheric carbon dioxide stored in peatlands has reduced the global temperature by approximately 1.5-2˚C (Holden, 2005; IBB, 2017). Considering that drained peatlands, only from the temperate zone, release, through peat oxidation, approximately 25 tons of carbon dioxide per hectare every year, the impact of these emissions is more than obvious (Șotropa, 2010; IBB, 2017).

Worldwide scientific assessments demonstrate that due to peatlands drainage, about 445,696 million tons of carbon dioxide were released into the atmosphere, of which 1298 million tons in 2008 alone (Joosten, 2009; IBB, 2017). Romania also contributed to this massive release, by decreasing its areas covered by peatlands in the last 10 years, because of human impact, by approximately 4% of its total peatland surface (Joosten, 2009; IBB, 2017).

The inclusion of most peatlands in Romania in the European network of Natura 2000 protected areas was an extremely positive thing and was done, especially, based on the studies published in 1960 by the renowned biologist Emil Pop. Later, under the effect of the extensive economic development, taken in Romania during the communist period, the studies on the peatlands present were few and disparate, not covering all the national territory nor the issues of rehabilitation, restoration, and conservation. In the evaluations made at the European level, relative and insufficiently documented data on these aspects are provided for Romania (Schumann & Joosten, 2008; Minayeva et al., 2009; IBB, 2017).

According to the national statistics, completed by the National Research and Development Institute for Environmental Protection and the Biology Institute of the Romanian Academy from Bucharest, in Romania, there are natural habitats of swamps and peatlands of community interest whose conservation is regulated by the Habitats Directive (DH). In this sense, among the ten types of such habitats listed in Annex 1 of the DH, eight types can be found in Romania, of which four types are acid peatlands (7110, 7120, 7140, 7150 codes) and other four types of alkaline bogs (7210, 7220, 7230, 7240 codes). This variety increases the importance of these habitats by prioritizing them for rehabilitation, reconstruction, conservation, and monitoring activities (INCDPM, 2013; IBB, 2017).

From the assessments made by the same two institutes, it appears that approximately 190 peatland sites in Romania require interventions to restore the balance within the ecosystem. The most intense pressures, which produce the most serious imbalances, are desiccation, drainage, development of invasive plants, and habitat fragmentation (Schumann and Joosten, 2008; Șerban et al., 2023).

A vital element for the existence and development of ecosystems, the hydrological regime favorable to them is closely conditioned by other natural factors, on which its evolution in time and space depends, such as precipitation, evapotranspiration, land cover, soils, petrographic substrate, etc. (Obropta et al., 2008; Sabău et al, 2017).

Due to the very close connection between the hydrological regime of the peatlands and their ecological benefits, the knowledge of their hydrology is imperative for the development of management solutions for their conservation and ecological reconstruction, but also to involve them in the action of flood mitigating (Monalto and Steenhuis, 2004; Obropta et al., 2008; Schumann and Joosten, 2008).

The present study aims to investigate how wetlands play a role in mitigating exceptional floods developed in their watershed and to consider this as a non-structural ecological solution for flood control (Bătinaș et al., 2014; Șerban et al., 2014).

Smolders et al. (2015) investigated the mitigation effects of estuarine wetlands under a storm surge in the Scheldt estuary (Belgium, The Netherlands) and concluded that a larger wetland generally brings more attenuation up to a threshold limit (Tang et al., 2020). Ameli and Creed (2019) investigated how the location of wetlands relative to the main stream network affects the hydrologic resilience of the Nose Creek watershed located in the Prairie Pothole region of North America. The authors concluded that wetlands closer to the main stream network played a more significant role in peak flow mitigation (Tang et al, 2020).

Very few studies have investigated the effect of wetland area and location on flood control, particularly for inland wetlands. This study aims to fill this gap by investigating the effect of the location and size (storage capacity) of wetlands on flood management (Tang et al., 2020).

The paper's goal is to model floods in response to a calculation of rain with a 1% probability of occurrence for several characteristic wetlands (case studies) within the Northwest Region of Romania, as part of a peatland restoration project (Sabău and Șerban, 2018). The aim is to identify the reaction and its efficiency in mitigating the maximum torrential runoff produced in the high mountain area (runoff formation area) or on its periphery (water outlet area under the effect of the hydraulic features of the terrain slope) (Veprakas et al., 2006; Tang et al., 2020). The methodology was applied to representative case studies, which reveal different/diversified conditions, both from the climatic, morphological, pedological, land cover, hydrological, etc. points of view.

1.2. Study area

In the current study, within the North-West Region of Romania, eight peatlands were analyzed, to which were added other two units related to the Buzău hydrographic basin, found in the central south-east part of the country within the Carpathian Curvature (Table 1, Figure 1).

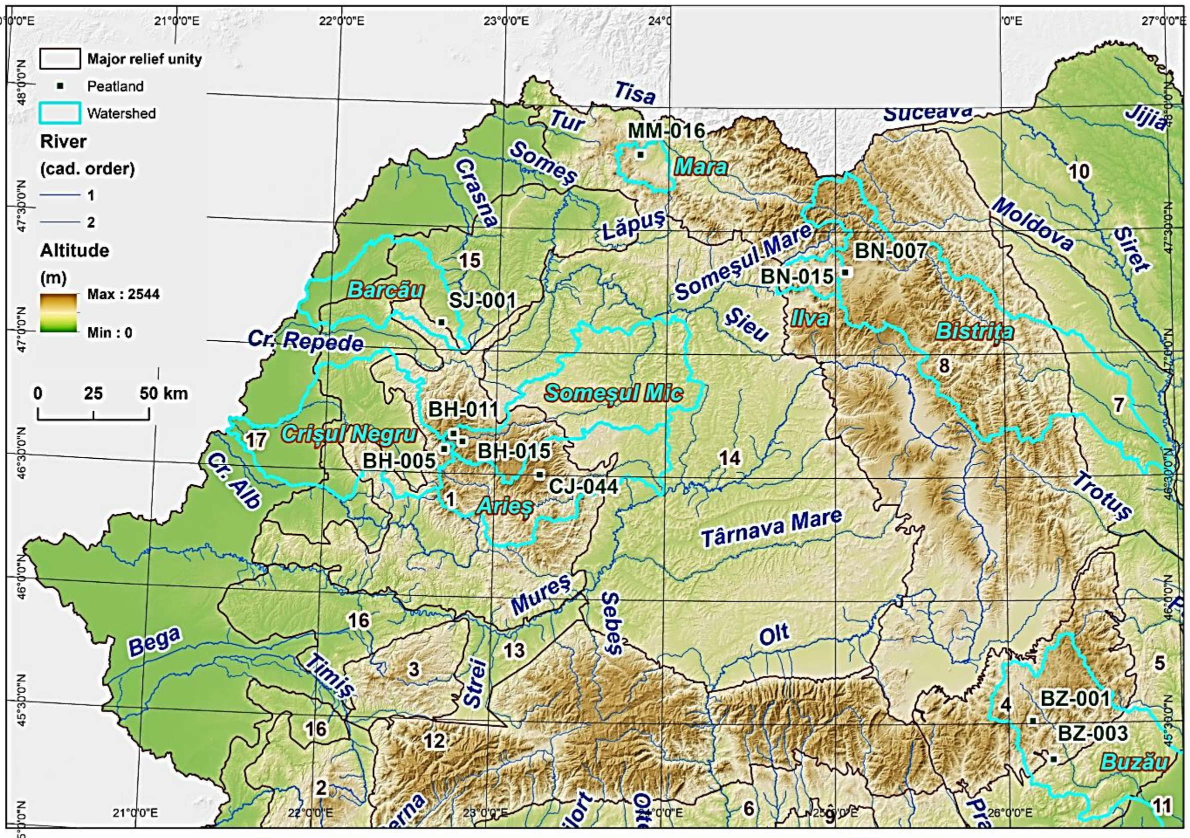
Table 1. Peatland's location according to major hydrographic basins and sub-basins.

No.	Peatland name	Peatland code	Water Basin Administration	Sub-basin
1	Tinovul Hărniceștilor	MM-016	Someș-Tisa	Mara
2	Tinovul Țesna Împuțită	BN-015	Siret	Bistrița
3	Tinovul Câmpeilor	BN-007	Siret and Someș -	Bistrița and Ilva
4	Mlaștina de la Iaz	SJ-001	Crișuri	Barcău
6	Turbăria Onceasa	BH-011	Someș-Tisa	Someșul Cald
7	Tinovul de la Ic Ponor	BH-015	Someș-Tisa	Someșul Cald
5	Turbăria de la Bălileasa	BH-005	Crișuri	Crișul Negru
8	Turbăria La Poduri	CJ-044	Mureș	Arieș
9	Turbăria Lacul Sec	BZ-001	Buzău - Ialomița	Buzău
10	Turbăria Lacul Manta	BZ-003	Buzău - Ialomița	Buzău

All these peatlands are part, either of the Carpathian area or of its neighborhood area, with a cool climate and variable humidity, as it will be shown, in the chapter related to the water balance.

Iezerul Mare (Tinovul Hărniceștilor) peatland - MM-016, located at 1004 m altitude, is included in the Igniș Mountains, a component of the northern half of the volcanic chain of the Eastern Carpathians, and is administratively located in Desești, Maramureș county. From a biogeographical point of view, the ecosystem is integrated into the upper nemoral layer, the peat being oligotrophic. Its surface is 11.62 ha.

Tinovul Țesna Împuțită peatland - BN-015, located at 893 m, is included in the Bârgău Mountains and is administratively located in Lunca Ilvei, Bistrița-Năsăud County. From a biogeographic point of view, the ecosystem is integrated into the boreal layer, the peat being mesotrophic. Its surface is 17.14 ha.



No.	Name	No.	Name
1	Apuseni Mountains	10	Moldavian Plateau
2	Banatului Mountains	11	Romanian Plain
3	Poiana Ruscă Mountains	12	Transylvanian Alps
4	Carpathians of Curvature	13	Orăștie-Strei Corridor
5	Sub-Carpathians of Curvature	14	Transylvanian Basin
6	Getici Sub-Carpathians	15	Western Hills (North of Mureș river)
7	Moldovei Sub-Carpathians	16	Western Hills (South of Mureș river)
8	Eastern Carpathians	17	Western Plain
9	Getic Plateau		

Figure 1. Location of NWPEAT wetlands and peatlands according to major morphological units of Romania (source altitudes EU DEM, 2018 and Topographic Map of Romania, 1978-1982).

Tinovul Câmpeilor wetland - BN-007, located at an altitude of 895 m, is included in the Bârgău Mountains and is administratively located in Lunca Ilvei, Bistrița-Năsăud County. From a biogeographic point of view, the ecosystem is integrated into the boreal layer, the peat being mesotrophic. Its surface is 17.23 ha.

Mlaştina de la Iaz wetland - SJ001, located at an altitude of 319 m, is included in the piedmont of the Plopiș Mountains and is located, from an administrative point of view, in Plopiș, Sălaj county. From a biogeographic point of view, the ecosystem is integrated into the thermos-nemoral zone, the peat being eutrophic. Its surface is 0.088 ha.

Tinovul Onceasa wetland - BH011, located at an altitude of 1335 m, is included in the Padiș karst plateau in the Bihor -Vlădeasa Mountains and is administratively located in Budureasa, Bihor County. From a biogeographic point of view, the ecosystem is integrated into the boreonemoral floor (spruce-beech mixture), the peatland being oligotrophic-mesotrophic. Its surface is 1.28 ha.

Tinovul Ic Ponor wetland - BH015, located at an altitude of 1040 m, is included in the Bihor Mountains and is administratively located in Budureasa, Bihor County. From a biogeographic point of view, the ecosystem is integrated into the boreal layer, the peat being oligotrophic. Its area consists of 4 isolated peats, with the following areas of 0.22, 0.39, 0.56, and 0.08 ha respectively.

Tinovul Bălileasa peatland - BH005, located at an altitude of 1236 m, is included in the Padiș karst plateau in the Bihor Mountains and is administratively located in Budureasa, Bihor County. From a biogeographical point of view, the ecosystem is integrated into the boreonemoral floor (spruce-beech mixture), the peat being mesotrophic. Its surface is 1.94 ha.

La Poduri wetland - CJ044, located at an altitude of 1600 m, is included in the Gilău-Muntele Mare Mountains and is administratively located in Valea Ierii, Cluj County. From a biogeographic point of view, the ecosystem is integrated into the boreal layer, the peat being mesotrophic. Its surface is 20.57 ha.

Lacul Sec wetland - BZ001, located at an altitude of 1463 m, is included in the Siriu Mountains and is administratively located in the communes of Chiojdu and Siriu, Buzau County. From a biogeographic point of view, the ecosystem is integrated into the boreal (spruce) floor, the peatland being mesotrophic. Its surface is 2.13 ha.

Lacul Manta wetland - BZ003, located at an altitude of 742 m, is included in the Buzău Subcarpathians and is administratively located in Chiojdu, Buzău County. From a biogeographical point of view, the ecosystem is integrated into the non-moral floor (beech), the peat being mesotrophic. Its surface is 0.93 ha.

2. MATERIALS AND METHODS

The study of wetlands (peatlands and swamps) in the North-West Region (associated to the NWPEAT project) was carried out based on documents from the Ministry of Environment, Water and Forests (MEWF), Regional Water Administrations (RWA) Someș-Tisa, Crișuri, Mureș, Buzău-Ialomița and Siret, and their subsidiaries in the territory, Water Management Systems (WMS) of following counties: Maramureș, Bistrița-Năsăud, Sălaj, Cluj, Bihor, Alba, Buzău and Suceava. The studies produced by the "Romanian Waters" National Administration (RWNA) and by its scientific forum, the National Institute of Hydrology and Water Management (NIHWM) were also consulted. In addition to these, documents from the National Meteorological Administration (NMA) or the ROCADA database were also consulted (Bîrsan and Dumitrescu, 2014; Dumitrescu and Bîrsan, 2015), which were updated. The mentioned documents (management plans, thematic studies, reports, etc.) were considered for the study, as they are continuously updated and are derived from the official water management activity conducted by the national authority and its basin subsidiaries.

For the analysis of the average runoff, necessary to achieve the *water balance* and establish the *hydro-climatic character of the studied areas*, the information provided from several hydrometric stations was used. The calculation period of the average runoff (1961-2021) was chosen based on several criteria, the most important being: the characteristics of the hydrometric data series, the accuracy of the data, and the degree of variability of the data series, etc.

The *extrapolation of data* related to the hydrological characteristics obtained from a relatively small number of hydrographic basins controlled by stations of the standard hydrometric networks to other basins lacking hydrometric information, to complete the strings, involved the use of suitable methods for this purpose (Diaconu and Șerban, 1994). The overlapping of the wetlands with the representative hydrographic basins, from the point of view of *hydrological syntheses and regionalization*, is shown in Table 1.

The *meteorological data* come from the nearest meteorological and hydrometric stations (Table 2). The data on air temperature and atmospheric humidity come from RWNA and NMA. The collected data refer to the daily average temperature and daily amounts of precipitation at the concerned stations during the entire year 2021, for the evaluation of the thermal and rainfall regime of each season.

Cartographic information and those of a *spatial* or *attribute* type, local or national/global, have been used to generate consistent mapping information needed for site analysis. The statistical series were integrated into the spatial support, for creating thematic maps particularly useful in the analysis and design of site area decisions for restoration purposes.

Table 2. The hydrometric and meteorological network near wetlands and peatlands.

No.	Peat code	Station name	Station type	Distance from peatland (km)	Station altitude (m)	Peat altitude (m)
1	MM-016	Mara	hydrometric	5	448	1010
2	BN-015	Poiana Stampei	meteorological	5	923	884
3	BN-007	Poiana Stampei	meteorological	5	923	884
4	SJ-001	Vâlcău de Sus	hydrometric	4.5	256	290
6	BH-011	Smida	hydrometric	4.5	1002	1030
7	BH-015	Smida	hydrometric	4.5	1002	1030
5	BH-005	Smida	hydrometric	4.5	1002	1030
8	CJ-044	Băișoara	meteorological	5	1360	1600
9	BZ-001	Penteleu	meteorological	23	1632	1464
10	BZ-003	Pătârlagele	meteorological	9.7	289	800

Some information comes from *the authors' research* conducted in wetland sites, in catchment areas, or river sections related to them.

The software used were those available at the Faculty of Geography of Babeş-Bolyai University and the Department of Geography and Department of Environmental Engineering at Valahia University (ArcGIS 10.x, Microsoft Office 2016, Corel Draw 8.x, etc.) or software and free/open-source platforms (USACE HEC, QGIS, Google Earth, etc.).

The simplified *water balance* was calculated for the study area, a particularly important indicator used to *identify areas with surplus or deficit of water* and in choosing case studies for mitigation modeling of maximum liquid runoff. For this purpose, the regionalization (spatial interpolations) was carried out for precipitation, the height of the runoff layer, evapotranspiration, runoff coefficient, and aridity index, extracting the tabular values for each watershed related to a wetland (Diaconu and Şerban, 1994; Sorocovschi and Şerban, 2012).

In the first form, the water balance equation was established by A. Penck in 1896 (1):

$$X = Y + Z \tag{1}$$

where: X – rain amount; Y – flow; Z – evaporation.

The average precipitation amount (X - mm) was obtained by regionalization (interpolation) based on points with measured values at meteorological stations, hydrometric stations, or rain gauging stations.

The height of the runoff layer (Y - mm) has been calculated with the relation (2):

$$Y = W/F \cdot 10^3 \text{ (mm)} \tag{2}$$

where: Y – runoff layer, in mm; W – drained water volume, in m^3; F – catchment surface, in km^2.

Evapotranspiration (Z - mm) was estimated using the Thornthwaite formula, which considers the air temperature value (equation 3) (Pereira and Pruitt, 2004):

$$\mathrm{ETP_i} = 16 \times \frac{\mathrm{L}}{12} \times \frac{\mathrm{N}}{30} \times \left(\frac{10 \times \mathrm{T_\alpha}}{\mathrm{I}}\right)^{\alpha} \tag{3}$$

$$\alpha = 6.75 \times 10^{-7} \times \mathrm{I}^3 - 7.71 \times 10^{-5} \times \mathrm{I}^2 + 1.792 \times 10^{-2} \times \mathrm{I} + 0.49239 \tag{4}$$

$$\mathrm{I} = \sum_{i=1}^{12} \left(\frac{\mathrm{T_{\alpha i}}}{5}\right)^{1.514} \tag{5}$$

where: ETP_i - potential evapotranspiration for *i* month;

T_a - average daily temperature (in °C, if this is negative enter the value 0);

N - the number of days in that month;

L - the average length of the day for that month (hours);

α - an exponent that is calculated with eq. 4;

I - local caloric index, which depends on the average temperatures of all months, obtained with eq. 5.

Runoff coefficient (η or Ks) was obtained with eq. (6):

$$\eta = Y/X\,; \quad \eta = \left(10^3 Q_i T\right) / \left(10^6 F X\right) \qquad (6)$$

where: η - runoff coefficient;

Y - runoff layer drained in *T period;*

X - volume of rain amount recorded in *T period* accumulated on *surface F*.

The aridity index (Ka) represents the ratio between the annual amount of evaporated water (Z) and the average annual amount of precipitation (X) (Sorocovschi and Şerban, 2012).

$$Ka = Z/X \qquad (7)$$

The first map of the aridity index in Romania was prepared by C. Ioan (1929). Later Ujvari and Gâştescu (1958) drew up the isoline map of the aridity index, based on which three humidity zones can be distinguished: rich (Ka < 0.8), variable (Ka = 0.8-1.2) and deficient (Ka > 1.2).

For the *hydrological modeling component* of the watershed, the HEC-HMS module was used, which simulates the precipitation-runoff processes in the wetland watershed (Veprakas et al., 2006; Tang et al, 2020). The latter was implemented in the HEC-HMS model as reservoirs (Tang et al, 2020).

For the *hydraulic modeling component* of streams within the watershed, which directs runoff from each subbasin through channels and produces flood results, the River Analysis System (HEC-RAS) was used to the necessary extent, depending on the area of watersheds (Veprakas et al., 2006; Tang et al, 2020).

HEC-HMS is a semi-distributed, process-based hydrologic model that can simulate various water quantity functions for multiple storage enhancement strategies at identified (existing and/or potential) storage sites (Scharffenberg et al. 2010; Zhang et al. 2013; Tang et al., 2020). HEC-HMS has the flexibility to explore the effect of multiple water management practices (ponds, wetlands, reservoirs, etc.) and can be easily integrated with the HEC-RAS model for flow routing and flood mapping (Tang et al., 2020). From the HEC-HMS model, flows entering rivers can be obtained from each sub-basin (with or without wetlands implemented). Outlets from each sub-basin are modeled as wetland inlets. For sub-basins without wetlands, runoff is modeled as lateral flows directly into adjacent rivers (Tang et al., 2020). For each wetland (reservoir) in HEC-HMS, the overflow feature is activated to simulate overflow using the broad-crested flow method. HEC-HMS simulates the change in water surface level and the change in storage in each wetland, as well as the overflows of each wetland, if they exist (Tang et al., 2020).

The hydrological model of the case study basins was developed in HEC-HMS, following several steps (Tang et al., 2020):

- the delimitation of the chosen hydrographic basins using a digital elevation model (DEM) with a resolution of 5 meters;
- the runoff estimation in each basin was done in HEC-HMS using the SCS(CN) method (unitary hydrograph method) (Chendeș, 2007 and 2011; Drobot, 2007).

Model calibration was done using the rational method, often used in Romania on small-level basins (< 20 km^2) (Diaconu and Șerban, 1994; Strapazan et al., 2023):

$$Q_{maxp\%} = 0{,}167 \cdot i_{p\%} \cdot \alpha \cdot F \qquad (8)$$

where: $Q_{maxp\%}$ - the maximum flow (m^3/s) with the probability of exceeding-insurance p%;

$i_{p\%}$ - the average intensity of rain (mm/min) with the probability p% that determines the maximum flow in the studied basin, having a duration equal to the concentration-time of the runoff;

α - runoff coefficient;

F - catchment area (ha).

The concentration time refers to the time required for the water to travel from the farthest point of the basin to the closing section, being represented by the time traveled by the water in its movement on the slopes and in the riverbed which is determined according to their lengths and related speeds (Diaconu and Şerban, 1994; Strapazan et al., 2023).

Two major hydrologic scenarios for modeling/simulation related to the studied wetlands and their associated watersheds were investigated in this study. *In the first scenario*, wetlands together with their ecosystems were considered as they exist in nature. The flows from each sub-basin are first directed to the wetlands, and when the wetlands are completely full, the overflows are then directed to HEC-RAS. *In the* *second scenario*, the wetlands are missing, their place being taken by a surface identical to that of the slope in the immediate vicinity. Streams from each sub-basin are fed directly into HEC-RAS (Tang et al., 2020).

3. RESULTS
3.1. Simplified water balance

Rain amount (X – mm) represents the indispensable conditioning parameter of runoff and the existence of wetlands. A simple analysis of their spatial distribution reveals two categories of areas with different concentrations of precipitation, which leave their mark on the functioning of the ecosystems in the studied wetlands (Figure 2).

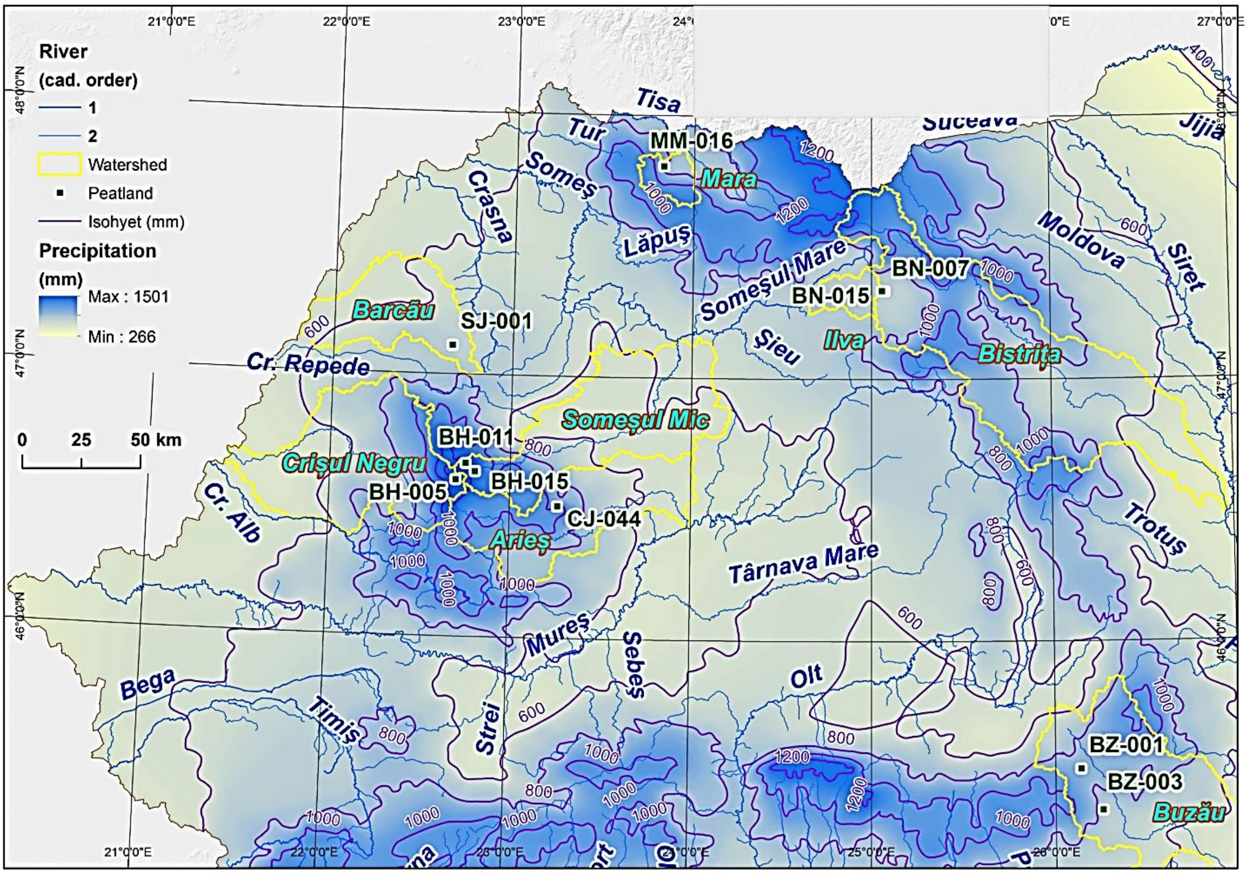


Figure 2. Map of multi-year average precipitation (adapted after RWNA, NIHWM, and NMA, 2021)

- the mountain area is characterized by average values exceeding 800 mm, even reaching 1200 mm; six of the ten wetlands studied are within the limits of this altitudinal and precipitation level;

- the hilly and depressions area, where the values drop a lot, up to 700 mm; four wetlands (SJ-001, BN-015, BN-007, and BZ-003) fall within this altitudinal and precipitation level; the effect on them is obvious, as will be seen below.

The **height of the average runoff layer** (Y – mm), represents the component related to the surface water drainage in the hydrographic basins, comparable to the precipitated layer. Wetlands BN-015, BN-007, SJ-001, CJ-044, BZ-001, and BZ-003 are located outside the areas with high runoff values (Figure 3).

Evapotranspiration (Z - mm), records a spatial distribution opposite to precipitation, being directly proportional to air temperature (Figure 4). Four wetlands (SJ-001, BN-015, BN-007, and CJ-044) make a discordant note compared to the rest of the studied areas, being in the gap of higher values of evapotranspiration (over 400 mm). The effect is visible in the water balance calculation.

The **runoff coefficient (Ks)** registers high values in the basins related to the studied wetlands, except for the SJ001 swamp (Figure 5).

In this particular case, the flow coefficient represents the torrentiality degree of wetlands due to precipitations amount and favorable surface drainage parameters (clay or primary soil, steep slope, etc.), as the water drainage is not influenced like in the case of anthropogenic drainage, intended for the transformation of wetlands in the benefit of people.

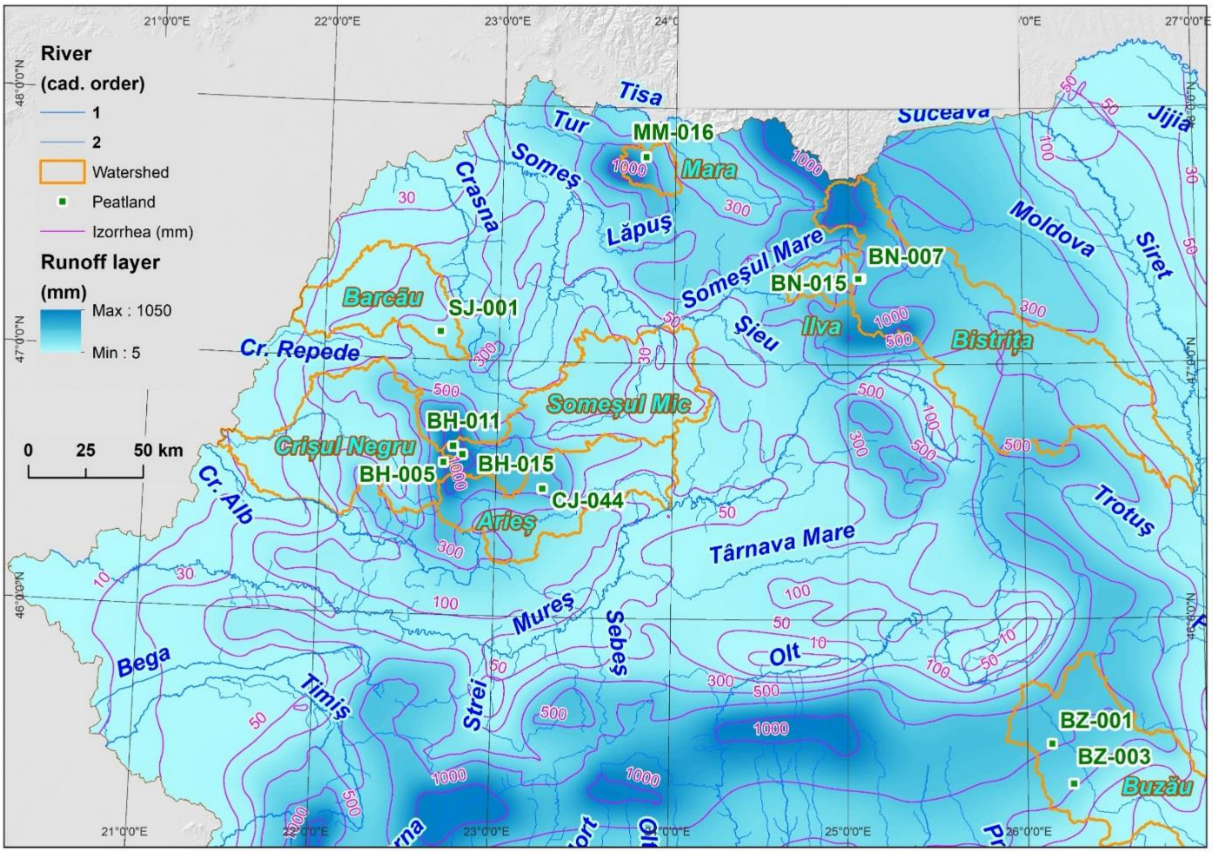


Figure 3. Map of the average runoff layer (adapted after RWNA and NIHWM, 2021).

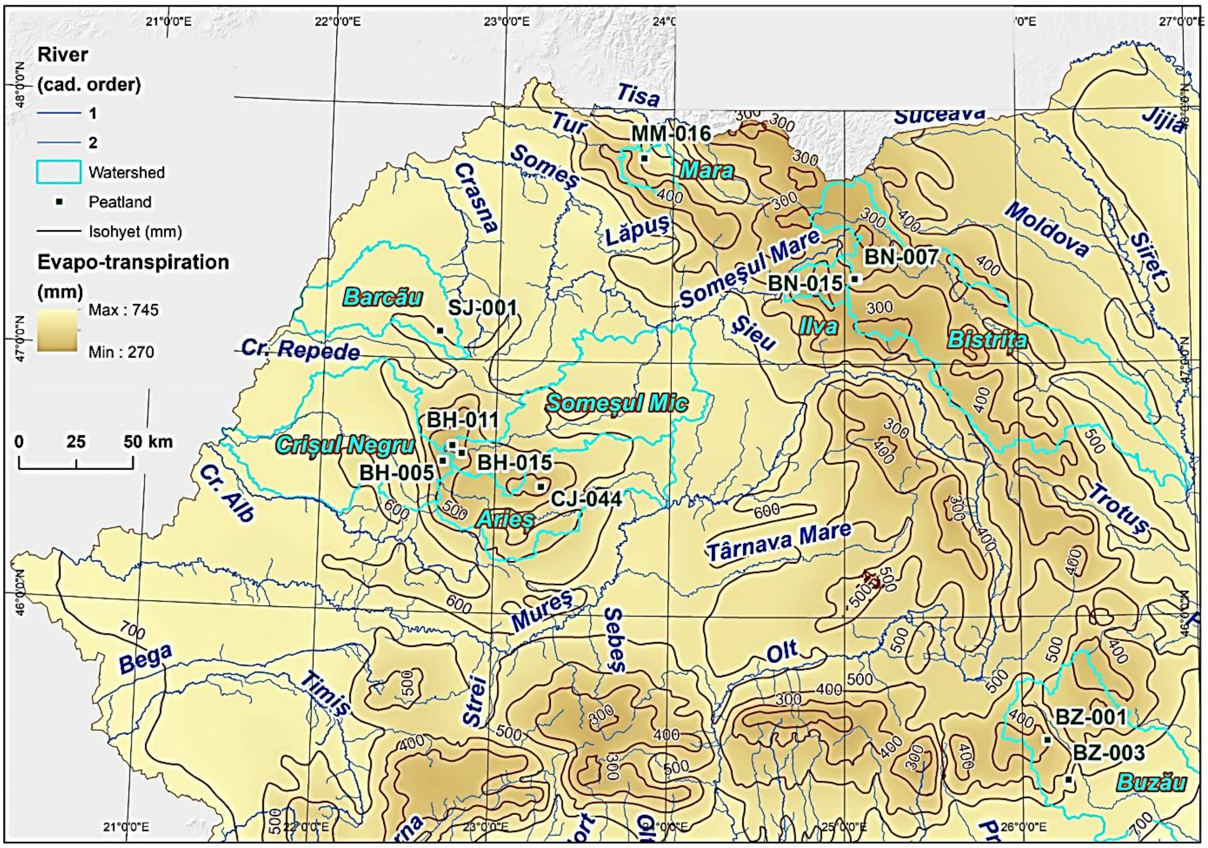


Figure 4. Map of multi-yearly average evapotranspiration (adapted after RWNA, NIHWM and NMA, 2021).

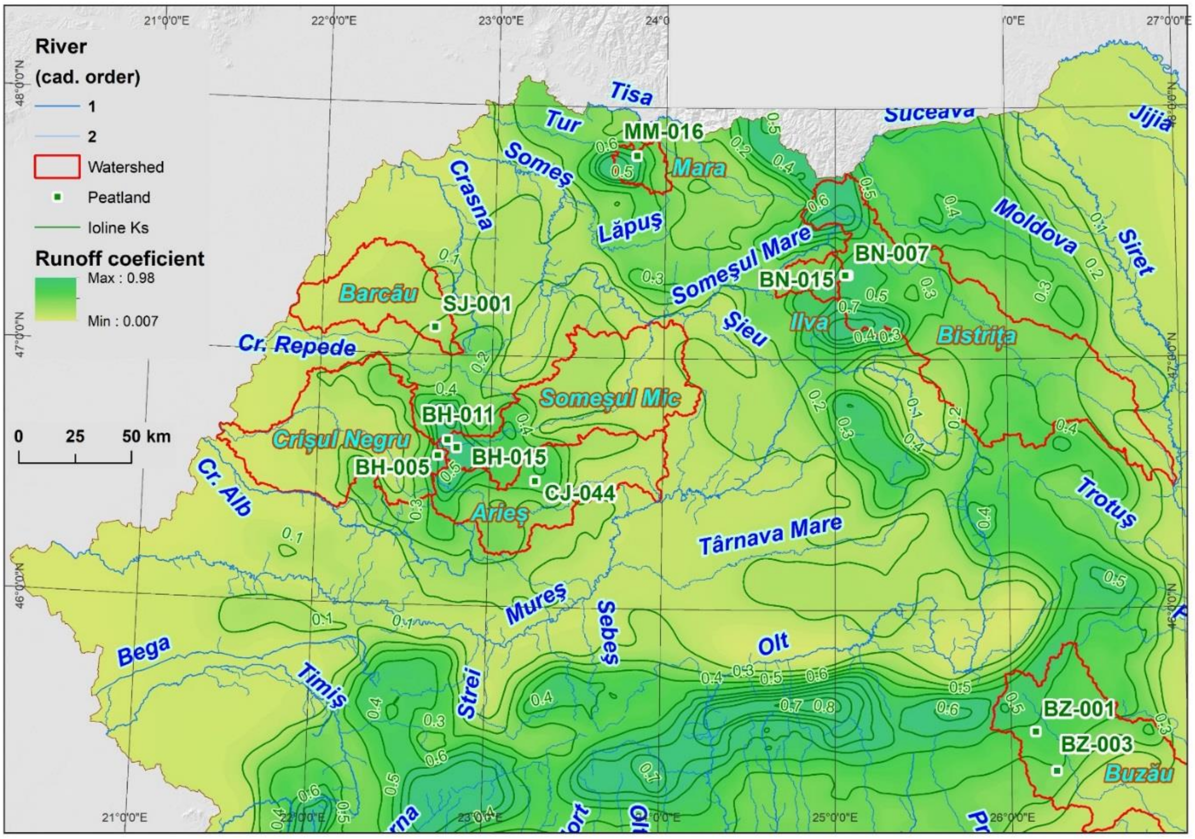


Figure 5. Map of runoff coefficient (adapted after RWNA and NIHWM, 2021).

The **aridity index** (Ka) is a truly relevant element that defines the character of an area in terms of its humidity degree (Figure 6, Table 3).

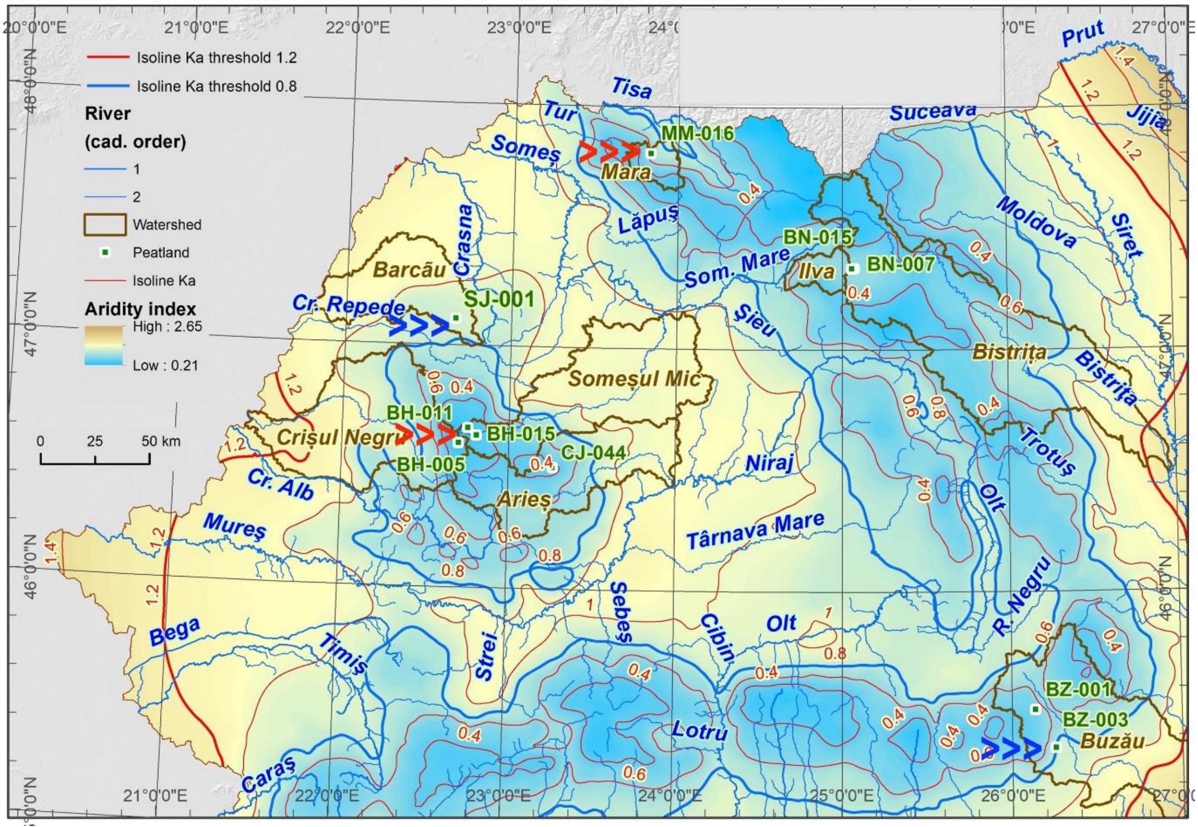


Figure 6. Map of the aridity index (adapted after RWNA, NIHWM, and NMA, 2021).

The threshold isolines of 0.8 and 1.2, presented in the *methodology chapter*, represent relevant marks regarding the location of the studied sites in the humidity categories. In this sense, the area of excess moisture (values of Ka between 0-0.8) leaves out only SJ-001 peatland, while BZ-003 peatland is located at the border of excess and variable moisture (marked on the map with an isoline of 0.8).

Table 3. Water balance related to receiving watersheds of NWPEAT wetlands.

No.	Peatland code	F (ha)	Precipitation (X)		Runoff layer (Y)		Evapotranspiration (Z)		Runoff coefficient Ks	Aridity index Ka
			mm	mil. m^3	mm	mil. m^3	mm	mil. m^3		
>>>1	**MM-016**	**33.53**	**1157.87**	**0.39**	**928.8**	**0.31**	**229.07**	**0.08**	**0.80**	**0.20**
2	BN-015	24.83	700	0.17	287.99	0.07	412.01	0.1	0.41	0.59
3	BN-007	78.34	700	0.55	288.15	0.23	411.85	0.32	0.41	0.59
>>>4	**SJ-001**	**5.33**	**700**	**0.04**	**149.9**	**0.01**	**550.1**	**0.03**	**0.21**	**0.79**
5	BH-011_1	3.48	1200	0.04	940	0.03	260	0.01	0.78	0.22
	BH-011_2	3.13	1200	0.04	940	0.03	260	0.01	0.78	0.22
6	BH-015_1	1.24	1100	0.01	914	0.01	186	0.001	0.83	0.17
	BH-015_2	4.31	1100	0.05	914	0.04	186	0.01	0.83	0.17
	BH-015_3	11.31	1100	0.12	914	0.1	186	0.02	0.83	0.17
>>>	**BH-015_4**	**13.83**	**1100**	**0.15**	**914**	**0.13**	**186**	**0.03**	**0.83**	**0.17**
7	BH-005	50.58	1200	0.61	850	0.43	350	0.18	0.71	0.29
8	CJ-044	112.68	1050	1.18	510	0.57	540	0.61	0.49	0.51
9	BZ-001	17.8	1000	0.18	690.12	0.12	309.88	0.06	0.69	0.31
>>>10	**BZ-003**	**7.16**	**700**	**0.05**	**373.34**	**0.03**	**326.66**	**0.02**	**0.53**	**0.47**

As peatlands of high altitude represent cooler and moister areas characterized by a specific ecosystem with a significant role for often rare species that live there, they can form sources of water supply for creeks in extreme drought scenarios.

The difference between the water volume entering and leaving an area represents the water reserve or the water balance calculation. The reference surface can be either a hydrographic basin, a lake, or a natural wetland unit (peatland/swamp).

The simplified water balance parameters of the wetlands from the northwestern region of Romania are presented in Table 3. Five of the wetlands (MM-016, BH-011, BH-015, BH-005 and BZ-001) do not exceed the high humidity limit of 0.31 Ka (Table 3, marked with the darkest color), four other wetlands (BN-015, BN-007, CJ-044 and BZ-003) do not exceed 0.59 Ka (variable humidity character), while the last one (SJ-001) is at the border of high and variable humidity (0.79 Ka).

The global runoff coefficient (Ks) has approximately the same classification as the aridity index, although slight differences can be noted, determined by the surface permeability, the influence of some morphometric characteristics (slope, exposition), different land cover (forest essences), etc.

3.2. Modeling a calculation rain of 1% probability transiting NWPEAT wetlands

In order to model and simulate a P1% calculation rain, four wetlands were selected: MM-016, SJ-001, BH-015_4, and BZ-003 (Table 3). Some of the arguments about the selection made are as follows: (Veprakas et al., 2006; Tang et al., 2020):

- two units (MM-016 and BH-015_4) were chosen for their high-altitude location (over 1000 m), and high rain amounts (over 1000 mm), but situated in different morphological units, with distinct exposure, petrography, land cover, etc.;
- another two units (SJ-001 and BZ-003) are located in areas of low rain amounts (700 mm), close to the specific values of the high plains of Romania, for approximately the same reasons, the general moisture level being substantially lower;
- wetlands with a watershed developed in width or as circular as possible, an aspect that gives these surfaces a high torrentiality (SJ-001 and BZ-003) (Figure 7);
- the selection of wetlands and related watersheds characterized by a diversity of land cover, and important differences between grass and trees associations;

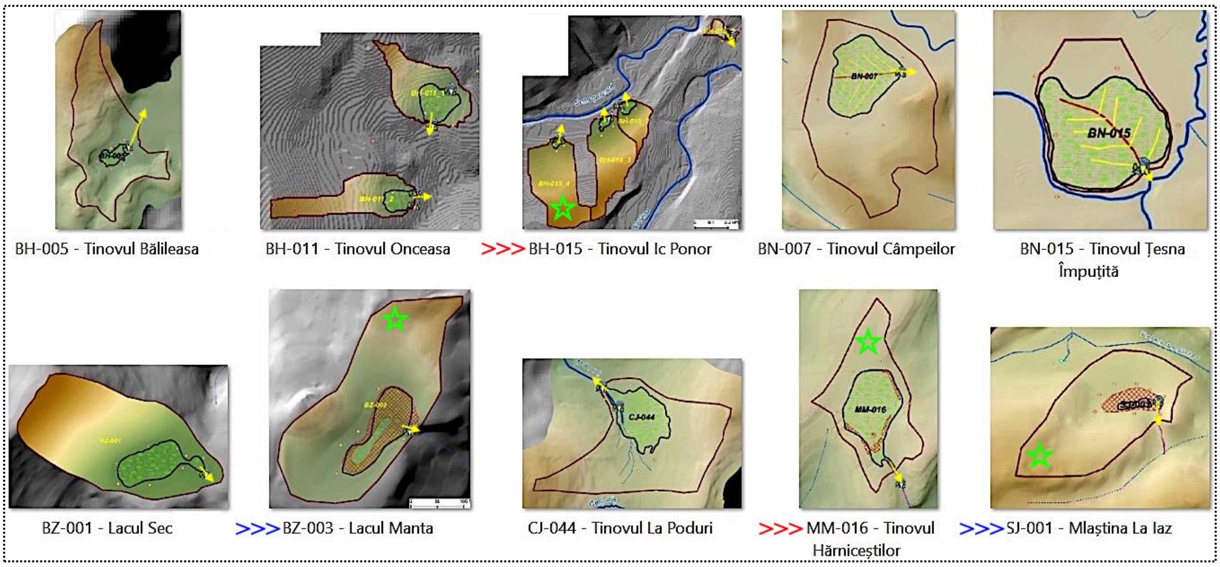


Figure 7. Cropping of NWPEAT wetland watersheds to establish the limit of case studies.

- selection of wetlands with different soil subtypes, for a different reaction within the performed hydraulic modeling, etc.

As mentioned in the *methodology chapter*, two major hydrologic scenarios were investigated for modeling/simulation, related to the studied wetlands. In the first scenario, wetlands and their ecosystems were considered exactly as they are (Figures 8.1 and 8.3; 9.1 and 9.3; 10.1 and 10.3; 11.1 and 11.3).

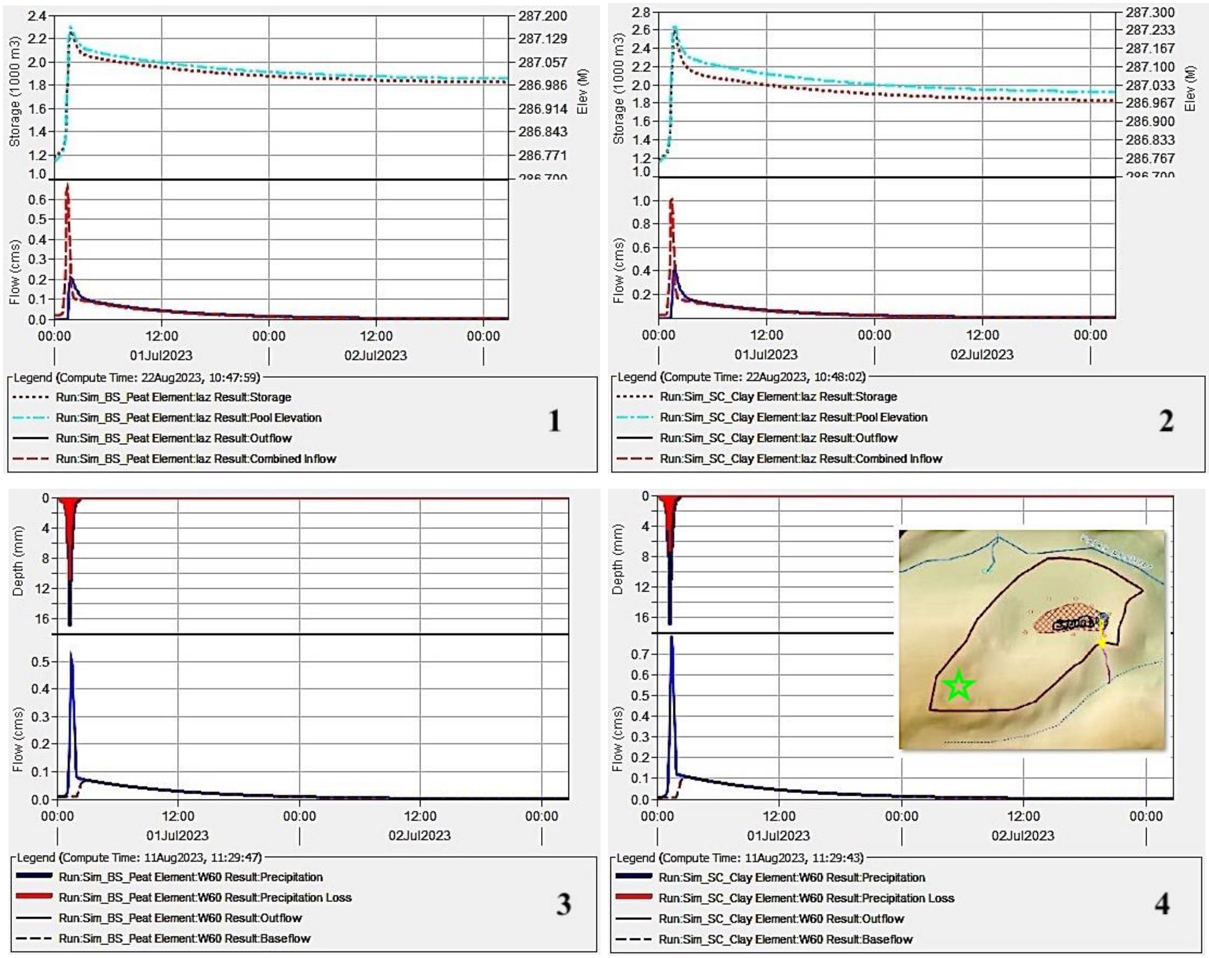


Figure 8. Maximum runoff modeling results of **Mlaştina de la Iaz** – **SJ001** wetland and the related watershed (1 - application to peatland with WL; 2 - application to peatland without WL; 3 - application to the entire watershed with WL; 4 - application to the entire watershed without WL).

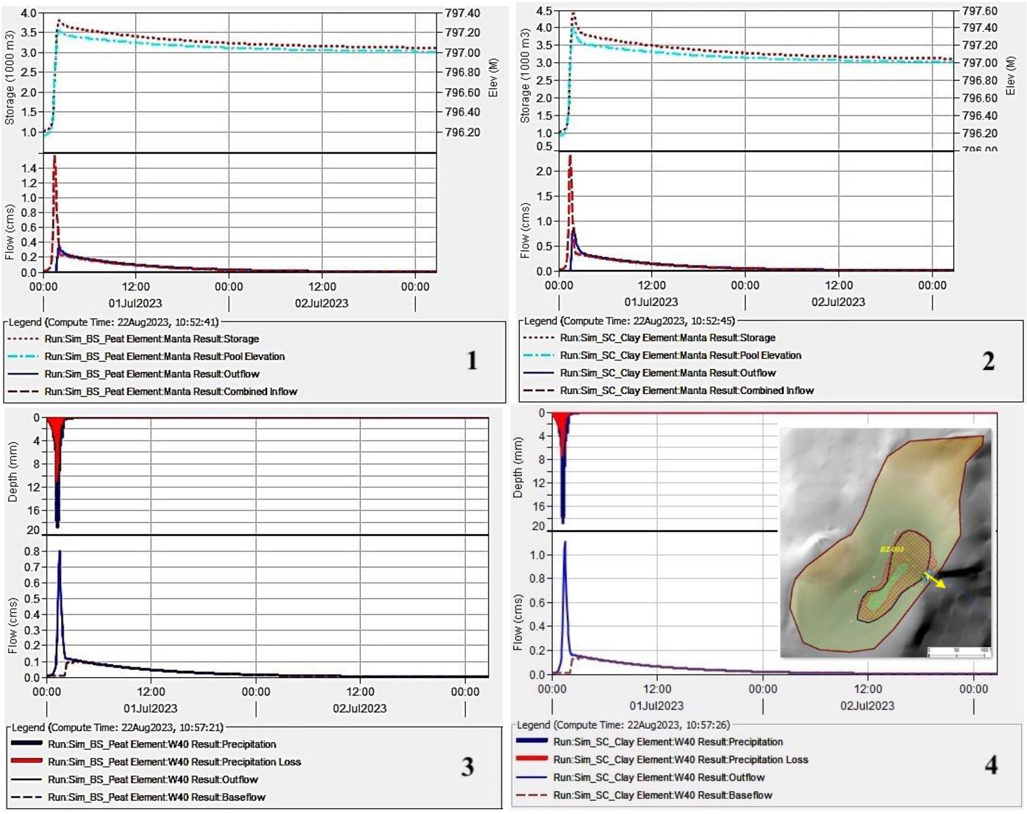


Figure 9. Maximum runoff modeling results of **Lacul Manta – BZ003** wetland and the related watershed (1 - application to peatland with WL; 2 - application to peatland without WL; 3 - application to the entire watershed with WL; 4 - application to the entire watershed without WL).

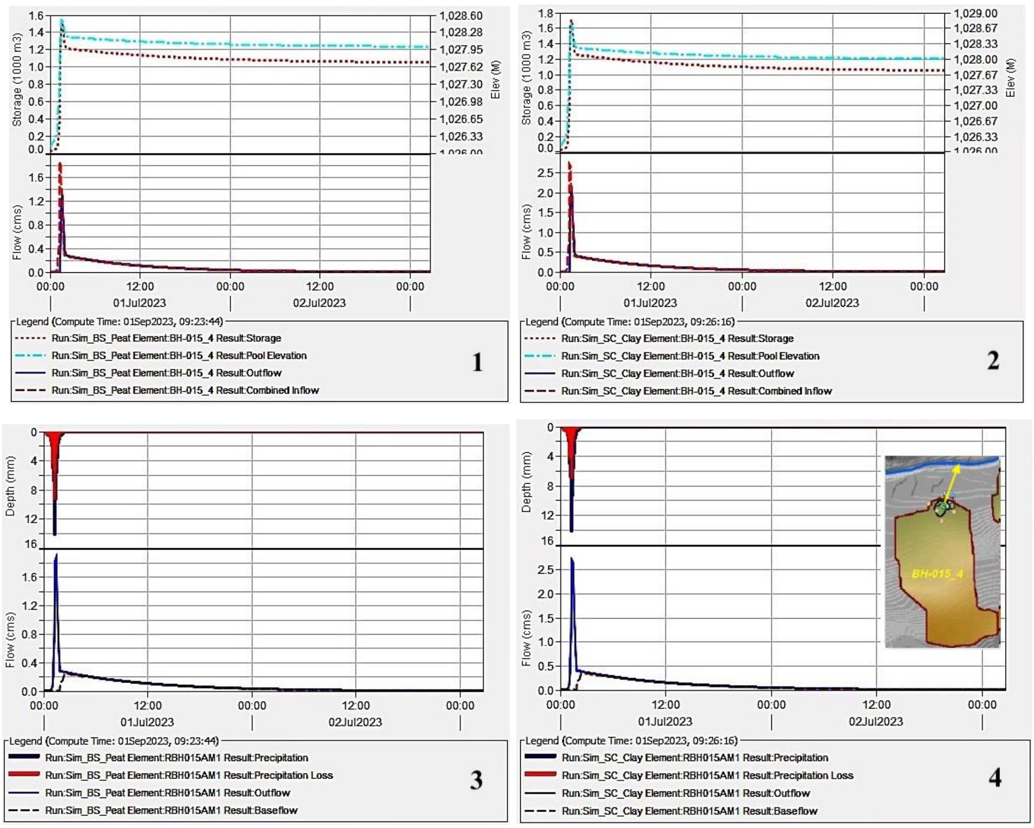


Figure 10. Maximum runoff modeling results of **Tinovul Ic Ponor – BH015_4** wetland and the related watershed (1 - application to peatland with WL; 2 - application to peatland without WL; 3 - application to the entire watershed with WL; 4 - application to the entire watershed without WL).

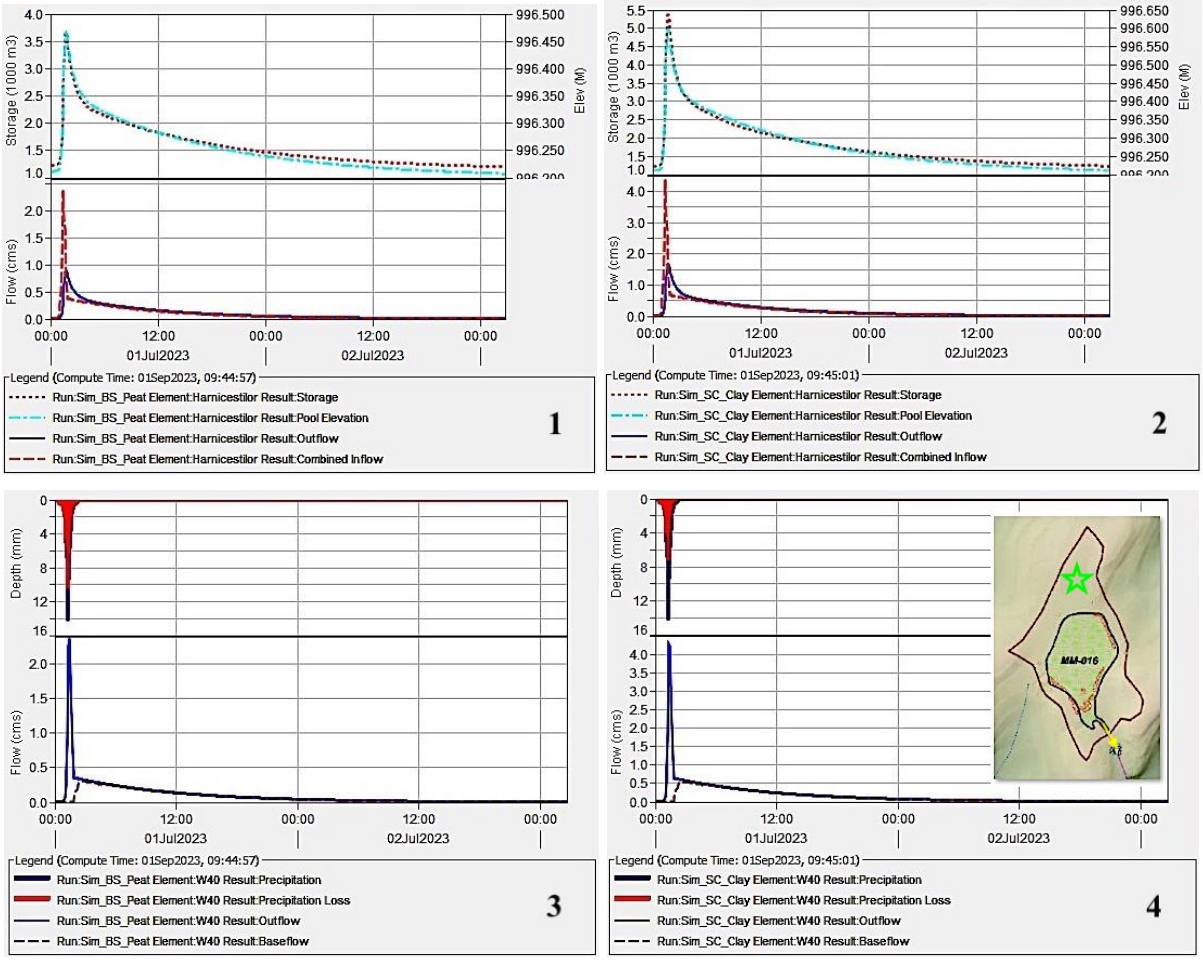


Figure 11. Maximum runoff modeling results of **Iezerul Mare (Tinovul Hărniceștilor) – MM-016** wetland and the related watershed (1 - application to peatland with WL; 2 - application to peatland without WL; 3 - application to the entire watershed with WL; 4 - application to the entire watershed without WL).

For all four selected wetlands, the plots show a good correlation between the water filling of the reservoirs (containing loaded with Sphagnum moss and other specific plant formations) at the low-probability rainfall pulse and the attenuation of input flows to the wetland system. The most significant attenuation of the inflow peak, reflected in the outflow peak, is found at selected wetlands in the hilly and variable moisture areas. Here, although the density of the forest carpet in the watershed is somehow lower and based on deciduous species, the morphometric characteristics of the basin and the related basins favor slower water transit. The water level in the peat bog is still relatively high even after the maximum flow of the flood has passed, due to the walling of the basin with quasi-impermeable clay material from the slope.

For higher altitude wetlands where moisture values and forest density are higher (especially the Tinovul Ic Ponor wetland – BH015_4), the correlation between basin filling and tributary flow mitigation is somehow weaker. The filling degree of the basin trough is slightly reduced, immediately after the maximum flow has passed, especially in the case of the Iezerul Mare (Tinovul Hărniceștilor) - MM-016 wetland, which is morphologically atypical, situated on a small secondary interfluvial arch. The attenuation of the maximum flow does not have the same intensity as in the case of the marshes from the hilly areas, with Tinovul Ic Ponor - BH015_4 wetland registering the lowest attenuation.

At the watershed level, the gap between the effluent base flow, originating from the underground, and the maximum effluent flow is preserved, both in the case of low-altitude marshes and those located at altitudes above 1000 m. The reason is the characteristics of the substrate, unfavorable to the accumulation of important water reserves (quasi-impermeable - clays, respectively magmatites/crystalline shales) and the thin and primitive or clayey soil layer.

In the second scenario, the wetlands are missing, and their place is taken by a surface identical to that of the hillside in the immediate vicinity (Figures 8.2 and 8.4; 9.2 and 9.4; 10.2 and 10.4; 11.2 and 11.4). The morphometric features of the missing basin area are, however, the same (slope, lack of major unevenness, etc.).

For the four selected wetlands, the plots demonstrate a weaker correlation between water filling of impoundments devoid of Sphagnum moss and other specific plant formations during the low-probability rainfall pulse and attenuation of input flows to the wetland system. The attenuation of the maximum influent flow, reflected in the maximum outflow, is noticeably weaker, basically more of a relatively fast transit of water through the reservoir basin. The water level in the basin drops more, after the maximum flow of the passed flood, due to the lack of massive roughness conferred, in the previous situation, by the hydrophilic vegetation and the faster access of water to the area of outflow from the basin/natural spillway (Brețcan et al., 2023). Practically is more of a surface attenuation, caused by the spread of flood water on the wide and low-slope surface of the basin, a phenomenon present in the case of reservoirs.

At the watershed level, the drained flow increases at the exit through the natural spillway by at least a third, and the gap between the effluent base flow, originating from the underground, and the maximum effluent flow is also amplified, both in the case of low-elevation marshes, as well as of those located at altitudes above 1000 m. This feature is determined by the same substrate, unfavorable for the accumulation of important water reserves.

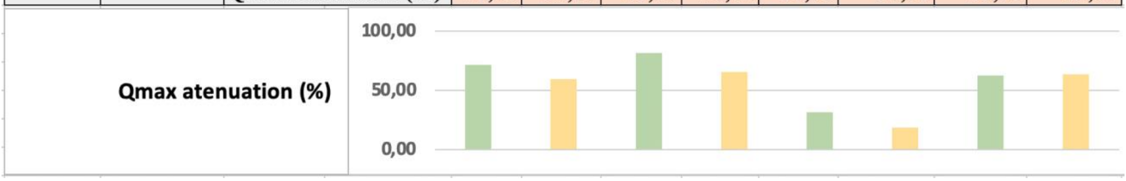
4. DISCUSSIONS

For a detailed analysis, regarding the resulting values generated through hydrological modeling, statistics were made at the level of each wetland and the level of their related watersheds (Tables 4 and 5).

On wetlands, the input element was represented by the precipitation amount (mm) and the maximum precipitation (mm) on the basin of each unit, and the output elements (generated to establish the degree of runoff mitigation) the variation of the water level in peatland basin (m), water volume variation in the basin (%) and mitigation degree (%) of peak runoff at the outlet of each unit.

Table 4. Some statistical parameters resulting from hydrological modeling of effective wetlands.

			Wetland name	**SJ001 WA**	**SJ001 noWA**	**BZ003 WA**	**BZ003 noWA**	**BH015_4 WA**	**BH015_4 noWA**	**MM-016 WA**	**MM-016 noWA**
Precipitation	**Full (mm)**			80,7		122,3		69,8		69,9	
Precipitation	**Maximum (mm)**			16,9		18,8		14,2		14,2	
Wetland	**Water level (m - Black Sea)**		**Begining**	286,8	286,8	796,2	796,2	1026,1	1026,1	996,2	996,2
			Maximum	287,2	287,3	797,2	797,4	1028,5	1028,8	996,5	996,6
			Water level rise (m)	**0,400**	**0,500**	**1,000**	**1,200**	**2,400**	**2,700**	**0,300**	**0,400**
			End	287,0	287,0	797,0	797,1	1028,0	1028,0	996,2	996,2
	Wetland water volume (m3)		**Begining**	1200	1200	1000	1000	300	300	1200	1200
			Maximum	2300	2600	3800	4400	1500	1700	3700	5400
			Water volume rise (%)	**91,67**	**116,67**	**280,00**	**340,00**	**400,00**	**466,67**	**208,33**	**350,00**
			End	1820	1835	3200	3210	1060	1065	1250	1260
	Liquid flow (m3/s)	**Wetland inflow**	**Begining**	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
			Maximum	0,700	1,000	1,600	2,300	1,900	2,700	2,400	4,400
			End	0,004	0,004	0,007	0,007	0,003	0,003	0,008	0,008
		Wetland outflow	**Begining**	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
			Maximum	0,200	0,400	0,300	0,800	1,300	2,200	0,900	1,600
			End	0,004	0,004	0,007	0,007	0,003	0,003	0,008	0,008
		Qmax atenuation (%)		**71,43**	**60,00**	**81,25**	**65,22**	**31,58**	**18,52**	**62,50**	**63,64**



Regarding *the variation of the water level in the peatland basin*, major differences are observed between the beginning of the flood, the moment of its maximum, and its end. In *the peatland scenario with the present WL ecosystem*, the level variation occurs within the gap of 0.3 - 2.4 m, depending on the morphological configuration of the basin and the vegetation density occupying its space. In *the identical area scenario*, *with no wetlands*, their place being taken by a surface identical geologically and in terms of land cover to that of the slope in the immediate vicinity, the variation of the water level in the basin is increasing within the limits of 0.4 - 2.7 m. Important to mention, as seen in the previous chapter, is the faster movement of water vertically, the emptying of this space becomes, more intense than in the presence of peat vegetation (Table 4).

The variation of volume in the WL area is somewhat similar, slightly different from one unit to another. The largest increase in volume occurs within the wetland BH015_4, in the scenario of no peatland ecosystem (466.67 %).

Undoubtedly, the element of maximum interest within the study is the establishment of mitigation degree produced by the studied wetlands on floods generated by rains with a low probability of occurrence (1%). The statistics obtained confirm the hypotheses from the literature according to which wetlands take part significantly in this transformation of the maximum runoff phase. The highest percentages belong to wetlands SJ-001 and BZ-003, with values above 71% and 81%, respectively, which means a significant difference between the inflow volume into the system and the outflow value. More modest percentages, but not negligible due to the mitigation effect, belong to the wetlands in the highlands (BH015_4). Of course, the areas studied, considered in the variant without the WL ecosystem, also achieve an attenuation, but with significantly lower percentages, a process based on the areal attenuation in the basin space, as mentioned in the earlier chapter. A special situation is offered by the MM-016 wetland, due to its position (slightly atypical morphologically, on a small secondary interfluvial dome), as previously mentioned. This partially confirms the rule validated in the case of the other WL and presents approximately the same percentage of flood mitigation, both in the case of the presence of the ecosystem and in the variant without it (around 63%), which is particularly important, when intense rainfall episodes occur.

For ***the related hydrographic basins***, the input element was represented by the same amount of precipitation (mm) and the maximum precipitation (mm) in the basin of each unit, and the output elements were water losses through infiltration, interception, etc., precipitation net (excess), surface flow (direct flow), base or underground flow and global flow (total flow). Both scenarios were taken into consideration also for the modeling conducted on hydrographic basins (Table 5).

Table 5. Statistical parameters resulting from the hydrological modeling of the wetland's slope basins.

Wetland watershed name		SJ001 WA	SJ001 noWA	noWA/ WA*100 (%)	BZ003 WA	BZ003 noWA	noWA/ WA*100 (%)	BH015 _4 WA	BH015_4 noWA	noWA/ WA*100 (%)	MM-016 WA	MM-016 noWA	noWA/ WA*100 (%)
Watershed area (ha)		5.33			7.16			13.83			33.53		
Precipitation (mm)	Full	80,7			122,3			69,8			69,9		
	Max.	16,9			18,8			14,2			14,2		
Loss (mm)	Full	52,4	38,0	72,4	67,0	45,1	67,3	45,4	35,9	79,1	50,3	36,2	71,9
	Max.	10,9	7,4	68,0	11,0	7,4	66,6	9,4	7,1	75,8	10,4	7,2	68,7
Excess (mm)	Full	28,3	42,7	150,9	54,5	77,3	141,8	23,4	33,0	141,0	18,8	32,8	174,6
	Max.	6,01	9,49	157,9	9,97	13,58	136,2	4,8	7,06	147,1	3,74	7,01	187,4
Direct flow (m3/s)	Full	2,9	4,7	162,1	5,1	7,2	141,2	10,4	14,6	140,4	13,2	23,4	177,3
	Max.	0,5	0,8	160,0	0,8	1,1	137,5	1,9	2,7	142,1	2,4	4,3	179,2
Base flow (m3/s)	Full	4,9	10,6	216,3	10,9	15,2	139,4	29,1	44,5	152,9	39,2	73,7	188,0
	Max.	0,1	0,1	100,0	0,1	0,1	100,0	0,2	0,4	200,0	0,3	0,6	200,0
Total flow (m3/s)	Full	8,3	15,4	185,5	16,2	23,7	146,3	41,1	60,9	148,2	52,9	98,4	186,0
	Max.	0,5	0,8	160,0	0,8	1,1	137,5	1,9	2,7	142,1	2,4	4,3	179,2

Except for losses, the percentages reach or exceed 100% in terms of the increase in modeled values for the identical area scenario to WL, which confirms the assumptions of the significant and quasi-unilateral effect in this analysis. In this case, the decisive role belongs to the hydrographic basins, whose natural flow-mitigating characteristics (forestry, soil and filtering substrate, etc.), together with positive anthropic interventions (dams for torrents mitigation, reforestation, etc.), can influence significantly the output flows after a consistent rain episode.

5. CONCLUSIONS

Wetlands are dynamic ecosystems where environmental factors influence both their structure and functions. Their functions are ensuring a suitable living environment for specific flora and fauna communities, mitigating flood waves by storing significant amounts of water and gradually releasing it, filtering water and improving its quality, as well as maintaining biodiversity, carbon, and water reserves, natural regulation of water levels and runoff for the downstream watercourses that are dependent on them, etc.

The role of wetlands in moderating climate change can be a major one, as peatlands accumulate approximately half of the soil's carbon reserve through their ability to absorb and store atmospheric carbon dioxide for a long period of time. The drainage of peatlands, followed by the release of carbon dioxide and methane gas, can have a significant impact on the increase in global temperature and the intensification of climate change.

The knowledge of the hydrological regime of wetlands is extremely important, for the development of the management solutions for their conservation and ecological reconstruction, but also for their involvement in the action of mitigating the maximum runoff phases. Most of them are in high-altitude areas, where usually the drainage systems are formed, or in the buffer zones, with drainage to areas of other altimetric and morphometric features.

The present study is focused on investigating the role of wetlands in mitigating exceptional floods occurring in their watershed, because of the calculated rain of 1% probability of occurrence. This may represent an ecological solution for non-structural flood control management for other watersheds, too.

The analysis was applied to representative case studies of wetlands found in different and diversified conditions of climatic, morphological, and pedological, land cover and hydrological features.

The case studies presented in the paper were selected by analyzing the main hydro-climatic parameters conditioning the runoff (including the water balance of the hydrographic basins involved), along with some other parameters such as morphological, morphometric, pedological nature, land cover, etc.

Two major hydrological scenarios for modeling/simulation were generated and applied to wetlands and associated watersheds, to obtain the maximum efficiency for highlighting the attenuation of runoff phenomenon through wetlands. In the first scenario, wetlands and their ecosystems were considered as part of the studied area, while for the second scenario, instead of wetlands a geologically identical surface in terms of land cover of the terrain from the immediate vicinity of the wetlands was considered.

In the first scenario, for all four selected wetlands, the analysis shows a good correlation between the water filling of the reservoirs (containing loaded with Sphagnum moss and other specific plant formations) at the low-probability rainfall pulse and the attenuation of input flows to the wetland system. The most significant attenuation of the inflow peak, reflected in the outflow peak, is found at selected wetlands situated in hilly areas with variable moisture amounts.

At the watershed level, the gap between the effluent base flow, originating from the underground, and the maximum effluent flow is preserved, both in the case of low-altitude peats and those located at altitudes above 1000 m. The reason is the characteristics of the substrate, unfavorable to the accumulation of important water reserves (quasi-impermeable - clays, respectively magmatites or crystalline shales) and the thin and primitive or clayey soil layer.

In the second scenario, for the four selected wetlands, the plots show a weaker correlation between water filling of impoundments devoid of Sphagnum moss and other specific plant formations during the low-probability rainfall pulse and attenuation of input flows to the wetland system. The attenuation of the maximum influent flow, reflected in the maximum outflow, is noticeably weaker, basically more of a relatively fast transit of water through the reservoir basin.

At the watershed level, the drained flow increases at the exit through the natural spillway by at least a third, and the gap between the effluent base flow, originating from the underground, and the maximum effluent flow is also amplified, both in the case of low-elevation marshes, as well as of those located at altitudes above 1000 m. This feature is determined by the same substrate, unfavorable for the accumulation of important water reserves.

For a detailed situation of the results from the hydrological modeling, statistics at the level of effective wetlands and their related watersheds were made.

At the wetlands level, the inputs were represented by the sum of precipitation (mm) and the maximum precipitation (mm) on the basin of each unit, while the outputs (for establishing the degree of mitigation of liquid runoff) consisted in the variation of the water level in peatland/swamp basin (m), the water volume variation in the basin (%), and degree of attenuation (%) of peak flow at the outlet of each unit. In the scenario of the presence of the wetland ecosystem, versus its absence, both the levels and the volumes of the water from the basins show significant increases following the transit of the influent volumes, while the effluent flow is attenuated in higher proportions.

In the related hydrographic basins, the input elements were represented by the amount of precipitation (mm) and the maximum precipitation (mm) in the basin of each unit, and the output elements were water losses through infiltration, interception, etc., the net amount of precipitation (excess), the surface flow (direct flow), the base or underground flow (base flow), and the global flow (total flow). Except for losses, the values for the other parameters reached or exceeded 100% in terms of the increase of the modeled values for the area scenario identical in size to the WL, but they are missing, which confirms the assumptions of the significant and quasi-unilateral effect in this analysis. In this case, the decisive role belongs to the hydrographic basins, whose natural flow-mitigating characteristics (forestry, soil and filtering substrate, etc.), together with positive anthropic interventions (dams to reduce torrents, reforestation, etc.), must be well represented.

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