How to cite: Bătinaș R., Șerban G., Sabău D., Brețcan P., Dunea D., Tudose T., Tanislav D. (2024) Hydrological Modeling of the Influence of Ecological Dams for the Restoration of the Water Regime in Peatlands - Case Studies. *2024 "Air and Water – Components of the Environment" Conference Proceedings*, Cluj-Napoca, Romania, p. 251-263, DOI: 10.24193/AWC2024_22.

HYDROLOGICAL MODELING OF THE INFLUENCE OF ECOLOGICAL DAMS FOR THE RESTORATION OF THE WATER REGIME IN PEATLANDS - CASE STUDIES

Răzvan BĂTINAȘ[1], Gheorghe ȘERBAN[1], Daniel SABĂU[1], Petre BREȚCAN[2], Daniel DUNEA[3], Traian TUDOSE[1], Dănuț TANISLAV[2]

ABSTRACT. Hydrological Modeling of the Influence of Ecological Dams for the Restoration of the Water Regime in Peatlands - Case Studies. The aim of this study is to model a rapid maximum runoff, response to a calculated rain with a probability of occurrence of 1% for several case studies within the Northwest Region of Romania, studied through NWPEAT project. The purpose of the study is focused also to identify the effect of raising ecological dams made of local materials in modifying the maximum torrential runoff at the outlet area from the peatlands sites. The methodology was applied to representative case studies, which revealed different/diversified conditions, both from the climatic, morphological, pedological, land cover or hydrological points of view. The first stage of the methodology focused on evaluating the inventory of the studied sites, the peatlands catchment features, their spatial analysis using morphological units and within the water balance, the analysis of runoff and aridity coefficients, etc. The modeling of the rain-runoff process was applied for two scenarios for each site, involving the presence or absence of the ecological dam. The results are quite dispersed from one case to another. Thus, we noticed a reduction in the maximum runoff of 70% in the case of the *Mlaștina de la Iaz peatland*, 40% in the case of the *Lacul Manta peatland* and only 8% in the case of the *Ic Ponor peatland* site. The difference between the three cases is made by the different patterns of some natural factors, among which are the peatland area, catchment area, shape of the basin and the slope, the degree of coverage with trees or less developed vegetation, the different layout of the sites compared to the flow directions of water vectors on the slope, etc.

Keywords: peatlands, North-West Region, hydraulic modelling, hydrograph, maximum runoff mitigation

1. INTRODUCTION

Swamps and peatlands, or wetlands in general, are dynamic ecosystems in which environmental factors influence both their structure and function. According to various authors, peatlands cover an area of about 400 million hectares in 180 countries on Earth, equivalent to 3% of the continental or island surface (Joosten and Clarke, 2002; IBB, 2017; Bătinaș et al., 2023). The role of wetlands is to ensure a

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[1] Babeș-Bolyai University, Faculty of Geography, Romania: razvan.batinas@ubbcluj.ro; gheorghe.serban@ubbcluj.ro; daniel.sabau@ubbcluj.ro; traian.tudose@ubbcluj.ro
[2] Valahia University of Targoviste, Faculty of Humanities, Department of Geography, Romania: petrebretcan@yahoo.com; dan.tanislav@valahia.ro
[3] Valahia University of Târgoviste, Faculty of Environmental Engineering and Food Science, Romania: dan.dunea@valahia.ro

suitable living environment for specific flora and fauna communities, mitigate flood waves events 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., 2023). Given the current climate context, their role can be a major one in moderating climate change, as peatlands store half of the soil's carbon stock through the ability to absorb and store atmospheric carbon dioxide in the long term. 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 patterns (Obropta et al., 2008; IBB, 2017; Koivunen al., 2023; Pettit et al., 2023; Bătinaș et al., 2023).

Worldwide scientific evaluations demonstrate that due to the drainage of these categories of surfaces, 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, where it is estimated that the areas covered by peatlands have decreased in the last decade, because of anthropogenic impact, by approximately 4% (Joosten, 2009; IBB, 2017; Bătinaș et al., 2023).

According to the national statistics, completed by the National Research and Development Institute for Environmental Protection Bucharest and the Biology Institute of the Romanian Academy in Bucharest, in Romania there are natural habitats of marshes and peatlands of community interest whose conservation is regulated by the Habitats Directive (DH). In this sense, among the 10 types of such habitats listed in Annex 1 of the DH, 8 types can be found on the territory of Romania, of which 4 types are acid peatlands (codes 7110, 7120, 7140, 7150) and 4 types of alkaline bogs (codes 7210, 7220, 7230, 7240), which increases the importance of these habitats by prioritizing them for rehabilitation, reconstruction, conservation and monitoring activities (INCDPM, 2013; IBB, 2017; Bătinaș et al., 2023).

The present study investigates the transfer of water through several peatlands in the Northwest Region of Romania, after the installation of some ecological dams, made of local materials, to raise the water level and restore the water balance in these systems.

The main objective of this paper is the modeling of a theoretical rainfall with a probability of 1% occurrence with the corresponding maximum runoff for several characteristic wetlands (case studies) within the mentioned region. The aim is to identify the reaction and efficiency of the ecological dams in supplementing the water reserve in the peatlands and their behavior when transited by some exceptional floods, with 1% occurrence probability (Veprakas et al., 2006; Tang et al., 2020; Bătinaș et al., 2023). The methodology was applied to three representative case studies with different natural features.

2. DATA AND METHODS

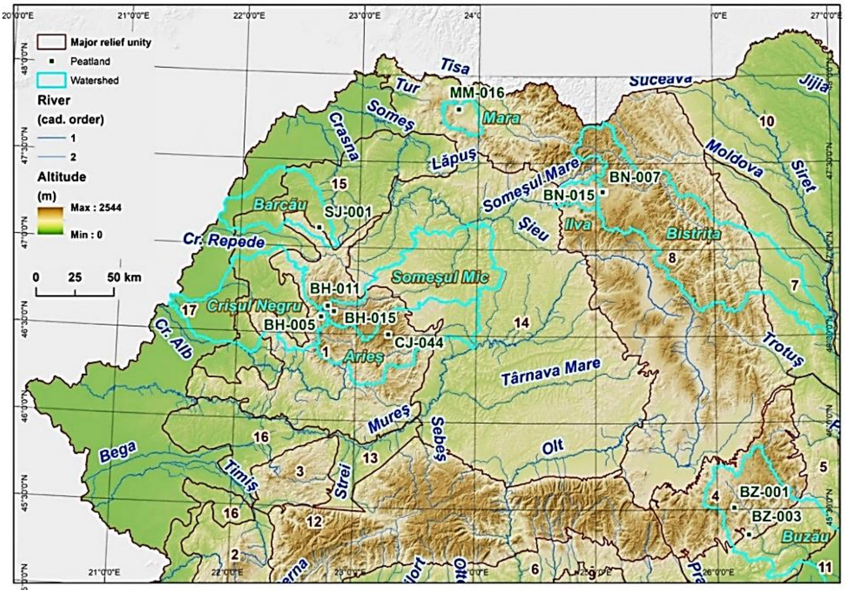
2.1. Study area

In order to carry out the study, within the North-West Region of Romania, a number of eight peatland-type wetlands were analyzed, to which were added two other units, from the same category, related to the Buzău hydrographic basin, located in the south of Moldavia (Table 1, Figure 1).

Table 1. Peatland's location according to major hydrographic basins and sub-basins (source: Bătinaș et al., 2023)

No.	Peatland name	Peatland code	Water Basin Administration	Sub-basin
1	Mlaștina de la Iaz	SJ-001	Crișuri	Barcău
2	Tinovul de la Ic Ponor	BH-015	Someș-Tisa	Someșul Cald
3	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 detailed, in the chapter related to the water balance.



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: Bătinaș et al., 2023; altitudes maps EU DEM, 2018 and Topographic Map of Romania, 1978-1982)

2.2. Preliminary used data

The study of wetlands (peatlands and swamps) in the North-West Region (associated to 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 carried out 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 were 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. (Bătinaș et al., 2023).

The extrapolation of data related to the hydrological characteristics obtained from a 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).

Table 2. The hydrometric and meteorological network near wetlands and peatlands (source: Bătinaș et al., 2023)

No.	Peat code	Station name	Station type	Distance from peatland (km)	Station altitude (m)	Peat altitude (m)
1	SJ-001	Vâlcău de Sus	hydrometric	4.5	256	290
2	BH-015	Smida	hydrometric	4.5	1002	1030
3	BZ-003	Pătârlagele	meteorological	9.7	289	800

Cartographic information was based on Copernicus EU DEM database and the national topographic map of Romania. The statistical series were integrated into the spatial support, for creating thematic maps particularly useful in the analysis of hydrological response of peatlands.

Some information comes from *the authors' own research* carried out in wetland sites, in catchment areas or river sections related to them with hydrological interest.

2.3. Methods

The software used for statistics purposes and mapping the resulted obtained 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.).

In order to establish the hydro-climatic patterns associated to the water balance of peatlands a complex spatial interpolation was done for generating several base features like precipitation, the height of the runoff layer, evapotranspiration, runoff coefficient and aridity index, including the extraction of tabular values for each watershed related to a wetland (Diaconu and Şerban, 1994; Sorocovschi and Şerban, 2012).

As an important feature of general water balance the *aridity index (Ka)* was used to evaluate the local situation for peatlands. This indicator represents a ratio between the annual amount of evaporated water (Z) and the average annual amount of precipitation (X) (Sorocovschi and Şerban, 2012).

$$Ka = Z/X \tag{1}$$

Ujvari and Gâştescu (1958) drew up the national 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 on the wetland watershed (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 3 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, frequently used in Romania on small level basins (< 20 km^2) (Diaconu and Șerban, 1994; Strapazan et al., 2023):

$$Q_{maxp\%} = 0,167 \cdot i_{p\%} \cdot \alpha \cdot F \quad (2)$$

where: $Q_{maxp\%}$ - the maximum flow (m3/s) with the probability of exceeding-insurance $p_{\%}$;
$ip_{\%}$ - 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).

3. RESULTS AND DISCUSSIONS

3.1. Pre-modeling considered features

As mentioned in the methodology chapter, the simplified water balance was calculated for the study area, important in identifying areas with surplus or deficit of water and in choosing case studies for modeling.

The aridity index (Ka) is a very relevant element that defines the character of an area in terms of its humidity degree (Figure 2, Table 3).

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 (Table 3). 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 isoline of 0,8 value). The BH-015 peatland is situated within the area with excess humidity (Bătinaș et al., 2023).

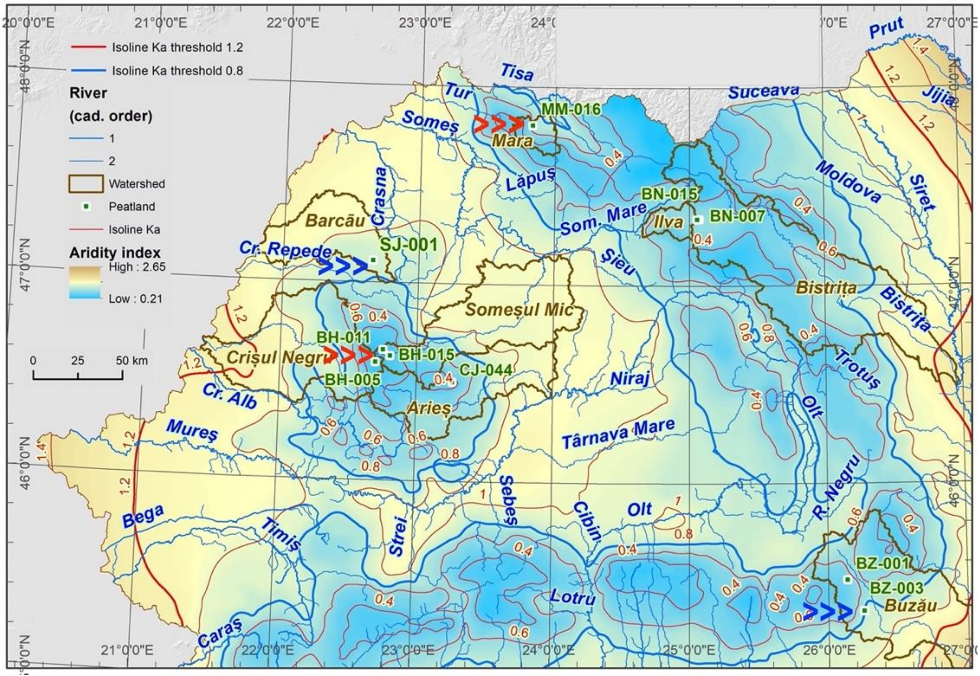


Figure 2. Map of the aridity index (source: Bătinaș et al., 2023; and adapted information from RWNA, NIHWM and NMA, 2021)

These elements reveal important information about the supply and maintenance of water levels (retention) within the peatland system. Also, by their very character of areas with a surplus of moisture and cooler, the high-altitude bogs/peatlands represent water reservoirs, which keep alive those specific ecosystems (Bătinaș et al., 2023).

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	**SJ-001**	**5.33**	**700**	**0.04**	**149.9**	**0.01**	**550.1**	**0.03**	**0.21**	**0.79**
2	**BH-015_4**	**13.83**	**1100**	**0.15**	**914**	**0.13**	**186**	**0.03**	**0.83**	**0.17**
3	**BZ-003**	**7.16**	**700**	**0.05**	**373.34**	**0.03**	**326.66**	**0.02**	**0.53**	**0.47**

3.2. Hydrological modeling of selected peatlands

Following the detailed analysis of the components of the water balance, but also of some components of a morphometric nature, three cases (SJ-001, BH-015_4 and BZ-003 sites) were selected for modeling based on precipitation with 1% probability of occurrence and the related maximum runoff generated (Bătinaș et al., 2023).

Some of the arguments regarding the selection made are presented below: (Veprakas et al., 2006; Tang et al., 2020):

- the BH-015_4 was chosen for its high-altitude location (over 1000 m), high rain amounts (over 1000 mm), with distinct exposure, petrography, land cover features etc.;
- the other 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);
- the selection of wetlands and related watersheds characterized by a diversity of land cover, and significant differences between grass and trees associations.
- selection of wetlands with different soil subtypes, for a different reaction within the performed hydraulic modeling, etc.

The modeling results reveal spectacular differences in terms of water drainage, after raising the water level in the peatlands, due to the construction of ecological dams made of local materials (figures 3-5).

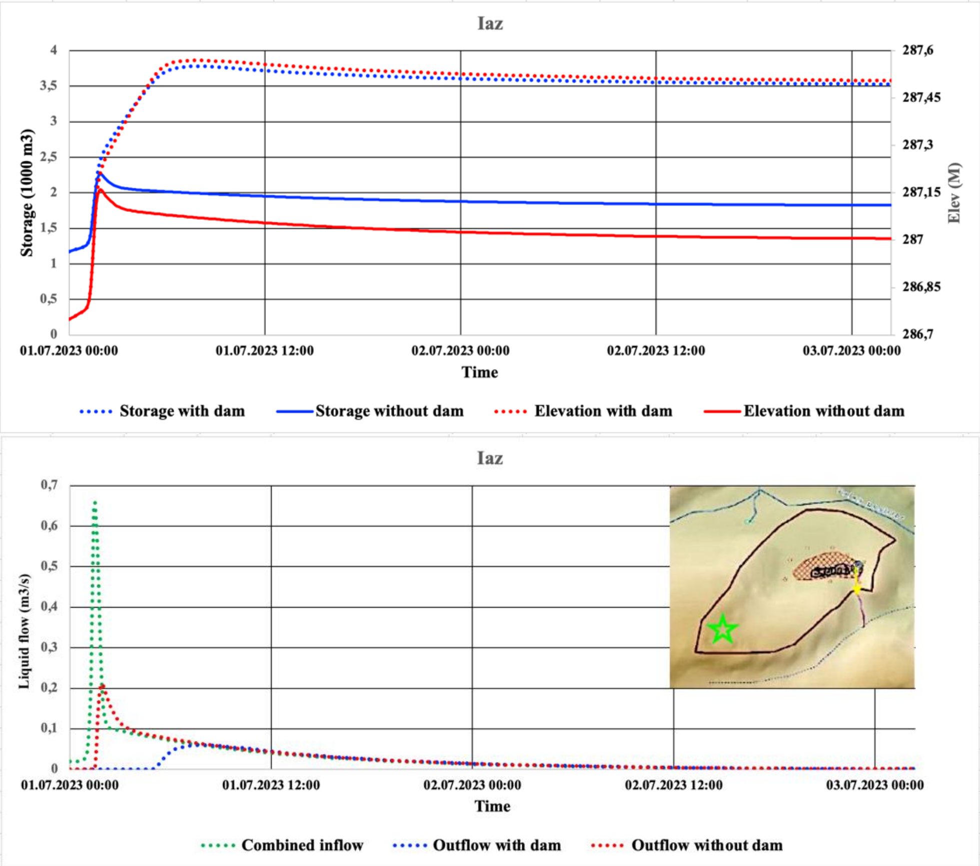


Figure 3. Modeling results of $P_{1\%}$ probability rainfall and associated peak runoff for the peatland Mlaştina de la Iaz – SJ001 and its catchment area.

In the case of the *Mlaștina de la Iaz peatland*, the level of water storage during rain and the generated calculated flood, as well as the volume of accumulated water, differentiates visibly, between the state of the peatland without an ecological dam and the one with the raised dam.

Even more interesting is the evolution of the outflows from the peatland. Due to the increase in the capacity of the basin after the dam building, the flow at the outlet looks completely attenuated, (just 0.060 m^3/s), while in the modeling scenario without the existence of dam the flow goes to more than 0.200 m^3/s. In percentage terms, this represents a reduction/mitigation of over 70% of runoff from the peatland system.

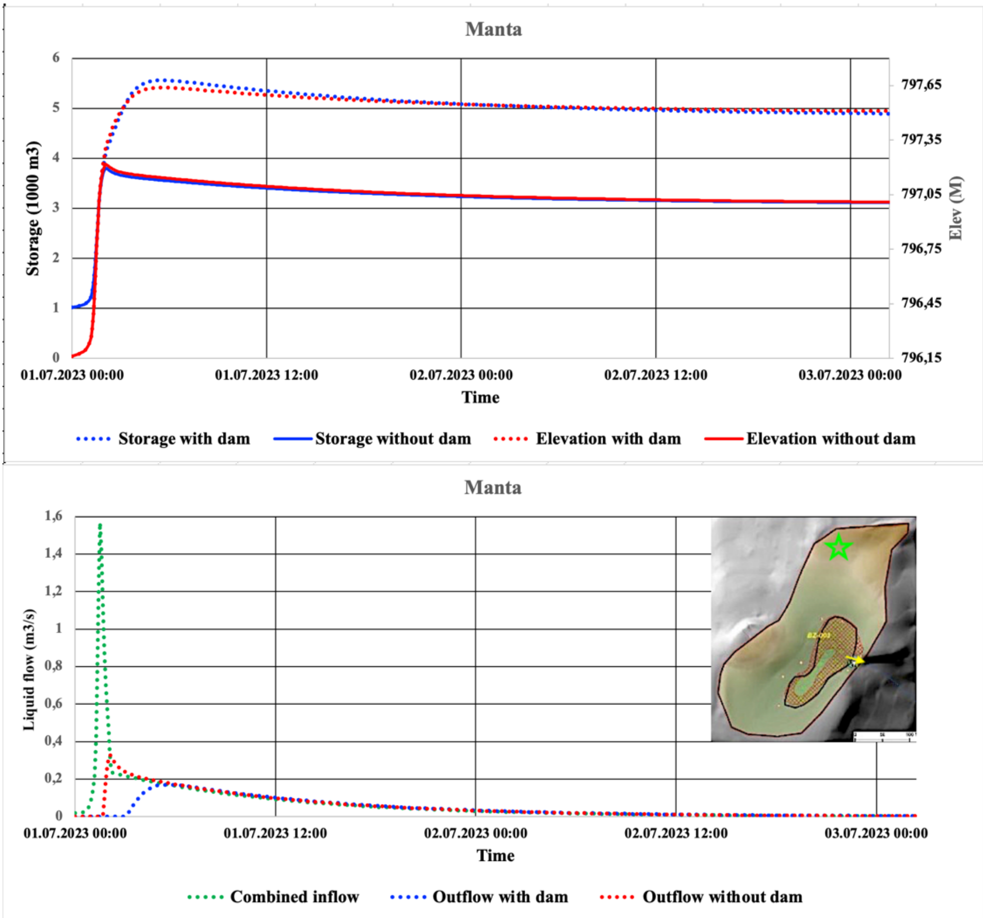


Figure 4. Modeling results of $P_{1\%}$ probability rainfall and associated peak runoff for the peatland Manta – BZ003 and its catchment area.

In the case of the *Manta Lake peatland*, the difference in the level of water storage during the period of rain and flood, as well as the accumulated volume of water, is kept well differentiated, between the state of the peatland without an ecological dam and that with the constructed dam.

The differentiated evolution of the outflows from the system is, as in the previous case, obvious. Due to the increase in the capacity retention of the peatland basin after the organization of the dam, the flow at the outlet looks consistently attenuated, (0.180 m^3/s), while in the modeling scenario without the existence of the dam the flow pulsation goes to more than 0.300 m^3/s. In percentage terms, this represents a reduction/mitigation of over 40% of runoff from the peatland system.

Compared to the previous case, the weaker attenuation is explained by the higher slope of the peatland catchment, corroborated with a not very consistent

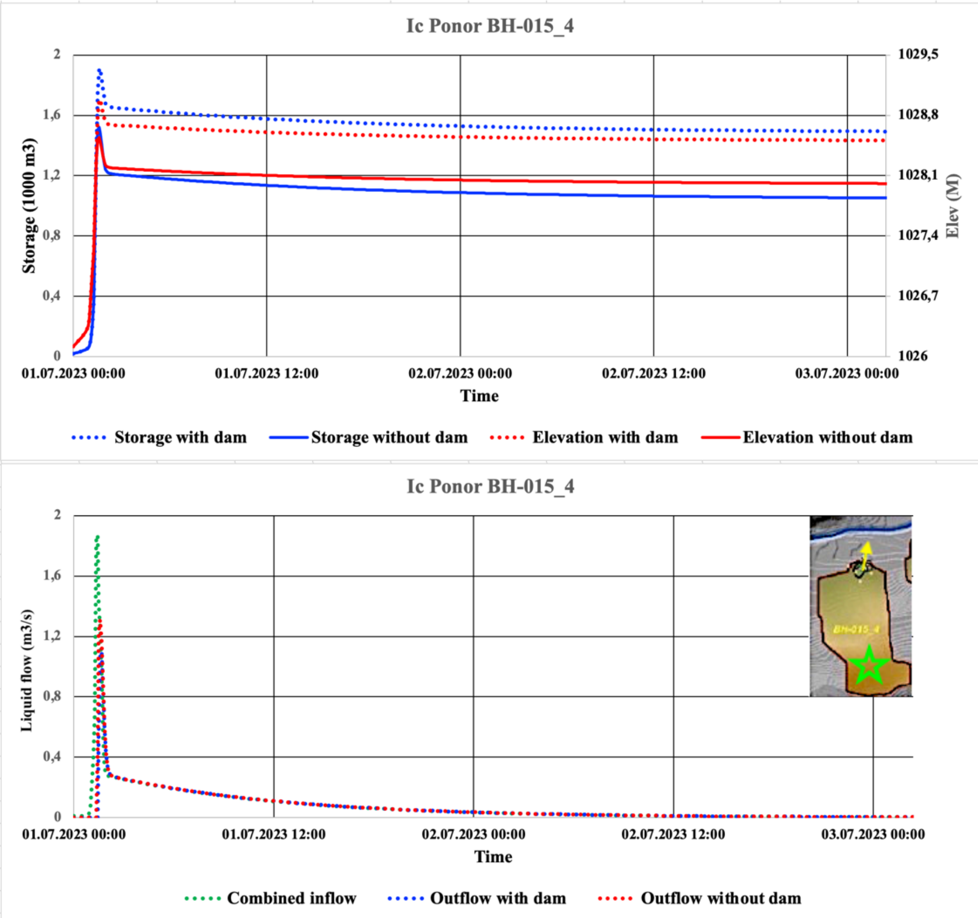


Figure 5. Modeling results of P1% probability rainfall and associated peak runoff for the peatland Ic Ponor - BH015_4 and its catchment area.

In the case of the *Ic Ponor peatland*, the difference in the level of water storage during the period of rain and the calculated flood, as well as the accumulated volume of water, remains consistent, between the state of the peatland without an ecological dam and that with the established dam.

The differential evolution of the outflows from the system is less obvious. Due to the increase in the capacity retention of the basin after the organization of the dam, the outlet flow reaches values up to 1.16 m^3/s, while in the modeling scenario without the existence of the construction, the maximum flow of the flood goes to more than 1.26 m^3/s. In percentage terms, this represents a reduction/mitigation of only 8% of runoff from the peatland system.

Compared to the previous cases, the much weaker attenuation is explained by the heavily forested surface with mature and dense trees of the watershed (massive attenuation of runoff in the watershed), combined with a generous watershed area and a longitudinal arrangement with respect to the directions of runoff of water vectors on the slope.

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 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 located 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.

Starting from these considerations, the present study focused on the investigation of the way in which the storage and circulation of water at the phase of extreme maximum runoff in/through the peatland system is influenced by the raising their capacity retention, through ecological small dams made from local materials.

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

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, have been used for the studied areas in order to prepare the input necessary data for the modelling process.

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, the hydrological modeling was carried out considering the presence of the dam, which raises the water outlet area from the peatland basin. The second scenario considered the free discharge of water from the peatland without any blocking items.

The modeling reveals interesting differences between the three case studies, with maximum runoff mitigation ranging from 70% for Mlaștina de la Iaz, to 40% in the Manta peatland, and only 8% in the Ic Ponor site. The difference in impact on the maximum runoff is conditioned by several factors, including the area of the catchment basin, the area of the catchment basin, the shape of the catchment and the catchment, the degree of cover with mature or less developed vegetation on the slope, the different arrangement of the sites in relation to the directions of runoff of water vectors on the slope, etc.

ACKNOWLEDGEMENTS

The financing of the publication of the article was provided by the project Restoration of wetlands and peatlands in the North-West Region (NWPEAT), coordinated by "Babeș-Bolyai" University Cluj-Napoca and in partnership with Norwegian Institute for Nature Research, no. contract DAFE 125170 / 16.12.2021, under the supervising of Program Operator Ministry of Environment, Water and Forestry of Romania.

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