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ALLOCATION OF FLOOD CONTROL CAPACITY FOR A MULTIRESERVOIR SYSTEM. CASE STUDY OF THE BISTRITA RIVER (ROMANIA)

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Abstract: The most intense floods occurred in Romania in the Siret river basin, more precisely, the Bistrita river basin. To minimize the risk of flooding, especially in areas that are not yet inhabited, it is, therefore, necessary to urgently draw up risk maps. In the present study, flood maps were drawn up for different probabilities and with a high degree of accuracy with the help of the ISIS (Integrated Spectrographic Innovative Software) modeling program, which was used as a system for modeling specialized issues of flood risk management. The hydraulic modeling uses the ISIS software products to control the hydrodynamics. To create the model with a reduced degree of error, topographical measurements were effectuated in the sectors, most frequently affected by floods. In the year 2015, the topographical surface was scanned using the LiDAR (Light Detection and Ranging) system.

Keywords: hydraulic modelling, flood risk map, ISIS LiDAR, Bistrita catchment.

1. INTRODUCTION

The climate changes caused by the increase of air temperature are a real phenomenon in the present time (Berz et al., 2001; Raška, 2015; Zeleňáková et al., 2015). At regional level, the effects of global warming can have catastrophic consequences like: ice melting in the Arctic zone, intensified torrential rain, increasing drought-affected areas, floods, flash floods, overflows, and so on (Conrad et al., 2015; Förster et al., 2008; Harris & Archer, 1999; Milevski et al., 2017; Radevski & Gorin, 2017; Pandyal & Syme, 1994; Sardou et al., 2018; Yang et al., 2014). Global climate changes have also led to an intensification of the research in Romania (Corduneanu et al., 2016; Mierla et al., 2015; Reti et al., 2014; Romanescu, 2013; Romanescu et al., 2018a,b,c; Türk et al., 2016;). Numerous studies have been developed with regard to thermal and pluviometric changes, and the effects of risk, especially those related to flooding (Biggin & Blyth, 2007; Birsan et al., 2012; Čech & Čech, 2013; Cojoc et al., 2014; Mihu-Pintilie et al., 2016; Mihu-Pintilie, 2018; Mic et al., 2015; Potcoava et al., 2010; Romanescu & Stoleriu, 2014; Romanescu et al., 2017a,b; Türk et al., 2016;).

The territory of Romania, in general, and that of Moldavia (NE Romania), in particular, belong to a transitional climatic zone. Due to oceanic influences the climate conditions present moderate values of the temperature and moisture than normal, and due to continental influences the climatic conditions can determine pluviometric and thermal discontinuities. In this context, the river basins from NE Romania are frequently affected by hydroclimatic change. Due to its location in the Eastern Carpathians, the catchment area of Bistrita river, under administration of the *Siret Water Basin Administration* (ABA Siret), is exactly at the area where these two climates come into contact (Barbulescu & Maftei, 2015; Gurung et al., 2009; Lehner et al., 2006; Tirnovan et al., 2014).

Generally, knowing the hydrological and flooding regime is required for the monitoring of the qua ntitative and qualitative parameters used in water resources management, but also for shielding against floods. The multi-annual average flow, which is determined by direct measurements at hydrometric stations, or using indirect methods like calculations and statistics, are the main values used in quantification of natural water resources. The minimum flow rates must be known for the application of restrictions on consumption and to ensure the salubrity and the servitude downstream. In the case of maximum flows, necessary safety measures must be taken for the hydro-technical works, especially for those designed for defense against floods. Between the phases of the runoff regime of rivers and the high risk, economic and social phenomena, the flash floods producing overflows and flooding, represent the major factors of natural risk (Romanescu, 2009; Romanescu & Nistor, 2011).

The approach with regard to flood mitigation was done, by considering the structural measures like: embankment works, channels designed to ensure the water drainage, complex works for attenuation of water retention, and so on. However, the structural measures can generate negative side effects: disattenuation phenomena, reservoir silting, local intensification of riverbed degradation and so on. Breaches of the legislation, along with the lack of concern for maintaining the capacity of riverbeds (during floods), has led to an illegal occupation of the meadow (frequently flooded lands). The floods of 1991, 1998, 2005, and 2010 confirmed cases of mismanagement of a well-equipped catchment area, in terms of hydraulic engineering (Siret Water Basin Administration, 2015).

Globally, experience has shown that the occurrence of floods cannot be avoided because floods are natural phenomena, with repeatability over time, at a certain scale, and form part of the normal circuit of run-off in the riverbed, and the only disasters that can be considered are those favored by man. However, flooding can be managed so that their effects are systematically reduced through measures and actions, aimed to diminish the risk associated with these phenomena.

Flood mitigation is more effective if you rigorously apply the non-structural measures: such as establishing areas of risk through various means and discouraging the population on occupying the territories which belong to rivers. The elaboration of flooding maps for different probabilities is a relatively old technique and, is an extremely detailed studies which have been undertaken at an international level (Berz et al., 2001; Chendes et al., 2015; Liu et al., 2015; Revuelto et al., 2014; Romanescu et al., 2018a,b,c; Sardou et al., 2018; Sevianu et al., 2015; Werner & Lambert, 2007; Yang et al., 2014) and also, at a national level (Costache et al., 2015; Cozma et al., 2015; Dumitriu, 2016; Luca et al., 2014; Mihu-Pintilie et al., 2014; Mihu-Pintilie, 2018; Romanescu et al., 2018b,c). Unfortunately, most of the flood risk maps for Romania were drawn into inappropriate scales or have used erroneous data from authorized institutions. LiDAR measurements taken in the Siret river basin can form the basis of studies with an extremely low error (Cojoc et al., 2015; Romanescu & Nicu, 2014; Romanescu et al., 2018b).

1.1. Case study. Geographic location of Bistrita river basin

The Bistrita River originates in Putreda and Bistricioara Rivers, which spring from Rodnei Mountains, at an altitude of 2,159 m. The two streams join to form the Bistrita River at 47°34'27" latitude North and 24°48'9" longitude East. The Bistrita River crosses the Eastern Carpathians on a length of 216 km and passes through 8 towns (e.g. Vatra Dornei, Piatra Neamt and Bacau). It flows into Siret River (9 km downstream of Bacău) becoming the longest river in Romania with a mountain trail (Cruceanu et al., 2015; Mihu-Pintilie, 2018; Romanescu & Bounegru, 2012; Romanescu et al., 2018b,c) (Fig. 1).

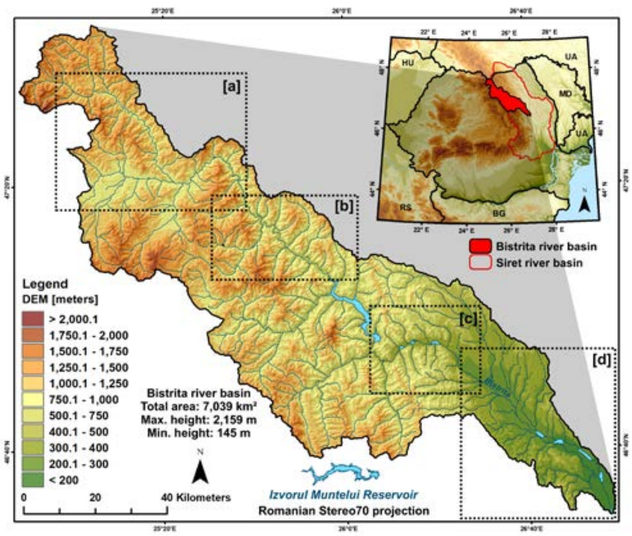

Figure 1. The geographic location of Bistrita wathershed within Siret river basin (NE Romania). The division of the study area: [a] upper sector of the Bistrita wathershed, [b] upstream and [c] downstream area of Izvorul Muntelui Reservoir, and [d] lower sector of the Bistrita wathershed.

The Bistrita River is the largest tributary of

Siret River and it is equipped with over 10 man-made reservoirs. The total length of the watercourse (with aquatic accumulations included) is 283 km. The catchment area is delimited by 24°47'55" long. E (west limit) and 27°00'49" long. E (east limit) and by 46°29'33" lat. N (south limit) and 47°44'42" lat. N (north limit). The total area of the watershed is 7.039 km² and collects over 200 tributaries such as Dorna, Neagra Sarului, Borca, Sabasa, Bistricioara, Bicaz, Tarcau, Cuejdiu, Cracau, and Trebes.

2. MATERIALS AND METHODS

The hydrological analysis is based on the measurements performed by ABA Siret. The daily, monthly and annual average values and the maximum values of liquid and solid flow for different measuring periods between the years 1950-2014 were calculated (Table 1). The climatic data are: the annual average values of temperature and precipitation from meteorological and pluviometric stations in the Bistrita river basin, as well as monthly values for some other monitoring points in the basin between the years 1950-2014 (Table 2). The cartographic basis is determined by the maps on scale 1:25,000, developed by the *Military Topographic Directorate* from Romania and from the ortophotoplans (2005, 2012 and 2015), developed by *ANCPI* Romania. In 2015, the LiDAR measurements have been completed for the most vulnerable areas of the Siret river basin. These data form the basis for drawing up the floodability maps with extremely low level of error. Cartographic materials have also been taken from the website http://srtm.csi.cgiar.org/ (CGIAR 2008) and DEM 30m (Digital Elevation Model).

Table 1. The hydrological data (*Q*: liquid flow; *R*: solid flow) recorded at the main stations within Bistrita river basin between 1956–2014

River	Hydrometrical station	Daily Values (Q)	Monthly Values (Q, R)	Annual Values (Q, R)	Qmed (m³/s)	Rmed (m³/s)
Bistrita	Carlibaba	1968-2014	1968-2014	1968-2014	7.45	-
Bistrita	Dorna Giumalau	1956-2014	1956-2014	1956-2014	12.0	2.10
Bistrita	Dorna Arini	1960-2014	1956-2014	1956-2014	25.1	4.52
Sabasa	Sabasa	1967-2014	1967-2014	1967-2014	0.937	-
Bistrita	Frumosu	1967-2014	1950-2014	1950-2014	38.1	7.82
Bistrita	Frunzeni	1977-2014	1977-2014	1977-2014	63.6	-
Tarcau	Cazaci	1990-2014	1990-2014	1990-2014	3.89	-
Bistrita	Straja	1986-2014	1986-2014	1986-2014	56.9	4.18
Carlibaba	Carlibaba	1986-2014	1986-2014	1986-2014	1.68	0.200
Dorna	Poiana Stampei	1986-2014	1986-2014	1986-2014	2.32	0.540
Tesna	Cosna	1974-2014	1974-2014	1974-2014	2.64	-
Bancu	Cosna	1976-2014	1976-2014	1976-2014	1.32	-
Dorna	Dorna Candreni	1959-2014	1959-2014	1959-2014	7.53	1.00
Dornisoara	Poiana Stampei	1986-2014	1986-2014	1986-2014	0.669	0.080
Neagra	Sura	1986-2014	1986-2014	1986-2014	1.18	0.260
Neagra	Gura Negrii	1986-2014	1986-2014	1986-2014	4.18	1.00
Haita	Gura Haitei	1987-2014	1987-2014	1987-2014	0.896	0.160
Sarisor	Panaci	1986-2014	1986-2014	1986-2014	0.686	0.054
Neagra	Brosteni	1965-2014	1965-2014	1965-2014	3.80	0.540
Bolatau	Poiana Largului	1978-2014	1978-2014	1978-2014	0.479	0.400
Putna	Tulghes	1966-2014	1966-2014	1966-2014	1.35	-
Bistricioara	Tulghes	1965-2014	1965-2014	1965-2014	3.10	0.770
Bistricioara	Bistricioara	1974-2014	1974-2014	1974-2014	6.25	2.72
Schit	Ceahlau	1978-2014	1978-2014	1978-2014	0.541	0.540
Bicaz	Bicaz Chei	1953-2014	1953-2014	1953-2014	2.73	-
Bicaz	Tasca	1988-2014	1988-2014	1988-2014	4.90	1.43
Cuejdiu	Cuejdiu	1989-2014	1989-2014	1989-2014	0.484	0.700
Iapa	Luminis	1965-2014	1965-2014	1965-2014	0.664	-
Cracau	Magazia	1974-2014	1974-2014	1974-2014	0.991	-
Cracau	Slobozia	1956-2014	1956-2014	1956-2014	1.80	2.30
Nechit	Borlesti	1977-2014	1977-2014	1977-2014	0.621	-

The data on the degree of afforestation is taken over from the *Corine Land Cover* 2006 and 2012 (Solín et al. 2011; Tirnovan et al., 2014). In order to achieve the proposed objective of this paper, it was required to process the entire database both statistically and graphically. For statistical analysis, the software used to process graphics and database was Microsoft Excel (XLstat) and Sigmaplot. For processing the GIS data and cartographic layers the ArcGIS 10.2 was used (Conrad et al., 2015; Pandyal & Syme, 1994; Romanescu et al., 2018a,b; Sardou et al., 2018; Sevianu et al., 2015; Werner & Lambert, 2007; Yang et al., 2014).

3. RESULTS AND DISCUSSION

Floods are the most common disasters on Earth and they produce the greatest material damage and loss of life. This being said, it is required to update the flooding hazard maps in order to achieve the management plans at the level of every main river basin. The loss of human lives has exerted a great pressure on the authorities to undertake precursory measures of stabilization or improvement in risk phenomena.

The current stage of management necessitates the awareness and involvement of the communities in order to minimize damage and avoid loss of life. Hazard maps are essential tools in flooding risk management strategy (Siret Water Basin Administration, 2015).

Flood risk management is the result of a whole complex of measures and preventive actions of an effective nature during floods or other measures and actions on post flooding reconstruction of what was affected and the awareness of its effects. The legislative pillars are: *Water Framework Directive 2000/60/EC* (Water Law 107/1996-Management Plan of the River Basins); *Floods Directive 2007/60/*EC (National Flooding Risk Management Strategy HG/846/2010-Plan of Flood Risk Management) (Nones, 2015).

The content of these framework directive and legislative pillars within the main river basin specifies the following requirements: 1. The primary identification of the sub-basin areas with significant potential risk from flooding, the probability of flooding occurrence from 10%, 1% or lower. Estimation of depth and water speed, the number of inhabitants potentially affected by any damage, and so on; 2. Structural facilities available for reducing the risk from flooding: reservoir with volumes reserved for flood control; unpermanent accumulations; flood mitigation; construction characteristics; technical and functional state of the constructions; the system of dykes: construction characteristics, degree of protection provided by the project, the current degree of protection, technical and functional condition; settlement of riverbeds and defenses of banks; 3. Flood risk maps; 4. Defining the degree of flood protection accepted; 5.

Table 2. Meteorological and pluviometric stations within Bistrita river basin used and the time periods for which data were available

River/Meteorological Station	Hydrometrical Station	Time periods for measurement
Bistrita	Carlibaba	1968-2003
Bistrita	Dorna Arini	1968-2003
Bistrita	Brosteni	1968-2003
Bistrita	Frumosu	1968-2014
Bistrita	Straja	1979-2014
Dorna	Poiana Stampei	1955-2003
Tomnatec	Dragoiasa	1968-2003
Sabasa	Sabasa	1971-2014
Bistricioara	Bilbor	1976-2014
Bistricioara	Tulghes	1976-2014
Bistricioara	Bistricioara	1968-2014
Bicaz	Bicaz Chei	1968-2014
Tarcau	Ardeluta	1969-2014
Cuejdiu	Cuejdiu	1968-2014
Cracau	Magazia	1976-2014
Cracau	Slobozia	1967-2014
Meteorological Station	Rarau	1968-2004
Meteorological Station	Cehlau Toaca	1950-2014
Meteorological Station	Piatra Neamt	1950-2014
Meteorological Station	Bacau	1950-2014

Description of structural actions, measures and solutions, and structural works necessary to achieve an adequate and accepted degree of protection against floods (Gno et al., 2004; Godlewska et al., 2003; Mihu-Pintilie et al., 2016). According to *The Plan for the Prevention, Protection and Mitigation of the Effects of the Floods*, implemented under administration of ABA-*Siret*, the main target is to generate flood risk maps recorded in Bistrita catchment area, as an integrated territory within the Siret river basin. The following activities: 1. Basic activities (conducting land and air measurements to ensure data for geometric integration support and subsequent delimitation of the areas more prone to flooding; 2. The development of a complex database and, managing them, using a specialized software and processing hydrological modelling; 3. For generating the maps of floodability (based on the calculation scenarios required); 4. Support activities (design and/or preparation of terrestrial and aerial measurements and a series of activities needed for the collection and/or to obtain specific data calibration process); 5. Ensuring the transfer of know-how for staff nominated by the client that can retrieve the results of the project (for the maintenance of database and keeping it up-to-date, including the maps of floodability), so all these have been implemented for achievement of this purpose. In subsequent years, a new set of maps of floodability will be updated and due to be completed in the year 2017 (Gaman, 2015).

The representativeness for the use of rain-drainage models as a pattern and tool to forecast or to detail and transfer the hydrological information is not very eloquent. Increased importance for this type of measurement can be found after the year 2000, when meteorology was separated from the hydrology. The highest degree of reliable data sets is represented by the hydrometric data, for level and flow measurements. Deficiencies only occur during periods with high level waters and with flash floods.

The level of water usage in the Bistrita river basin is intended primarily for industrial use and drinking water supply and secondarily for production of electricity (in combination with certain mitigation as protective measures against flooding). In terms of hydraulic engineering, the Bistrita River is the best planned hydro-technical basin from NE Romania. This database was used for generate the floodability study maps, which were drawn up for the areas of priority, that are differentiated in two levels of detail, A and B, plus some areas for the level C (Fig. 2).

For drawing up the floodability study maps: liquid flows, climatic data (temperature and precipitation), hydrographs, a hydrodynamic model and the flood levels were used. For the hydrodynamic model: topographic and hydrographic elevations, topographic and air measurements for the hydropower facilities was needed. In order to obtain the final result, each level of detail calls for certain requirements concerning the hydrological data, including the type of modelling and the scale of the final product: 1. The accuracy of the topographic data (DTM and aerial photographs): LEVEL A: horizontal precision: ±1-2 m; vertical accuracy: ±0.15 m; aerial photographs at 1:5,000 scale, which provides resolution of 10 cm (distance sampling, GSD) and allows the maps to scale 1:2,000; LEVEL

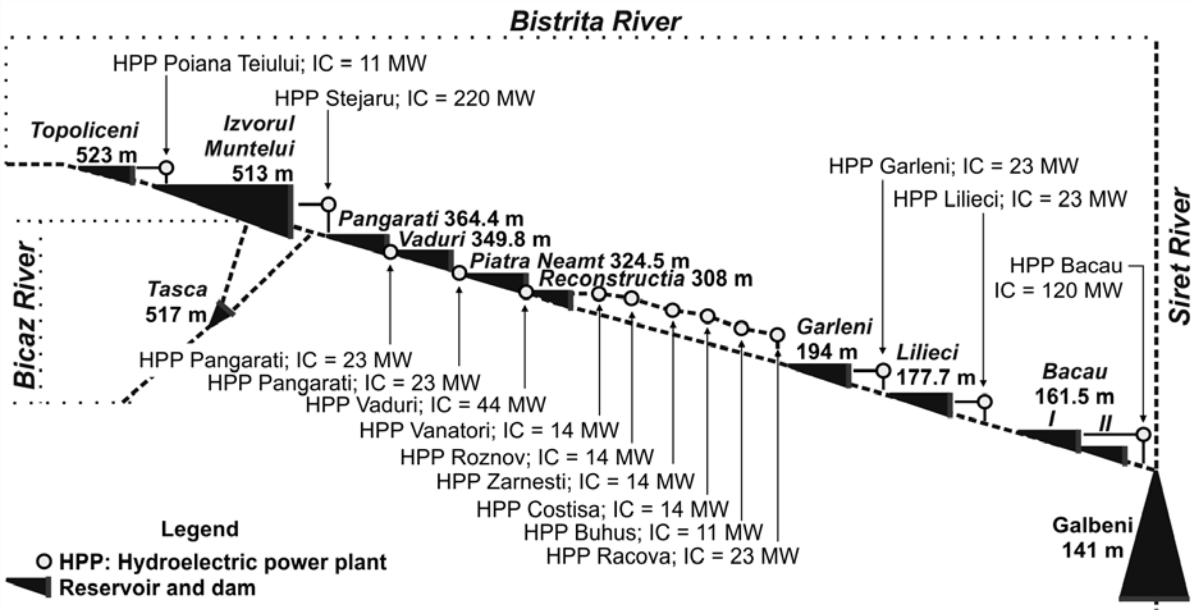

Figure 2. Hydroelectric power plant, reservoir, and dam scheme on the Bistrita River (Romanescu et al., 2018c)

B: horizontal precision: ± 5 m; vertical accuracy: ± 1 m; aerial photographs at 1:12,000, offering resolution of 0.25 m GSD and allows maps in scale 1:10,000; LEVEL C: horizontal precision: ± 25 m; vertical accuracy: ± 5 m; existing 1:50,000 maps and GIS (Geographical Information System) information updated and supplemented by aerial photos at scale 1:25,000, giving 0.54 m GSD of resolution and allow drawing up maps in scale 1:50,000 in areas with known changes; 2. The type of modelling used to generate the flood hazard maps are as follows: LEVEL A: 2D hydrodynamic modelling; LEVEL B: 1D hydrodynamic modelling; LEVEL C: hydrologic modelling; 3. Deliverables: LEVEL A: the flood hazard maps; LEVEL B: flood risk maps for - Siret, Suceava, Bistrita, Trotus, Putna, and Ramnicu Sarat rivers; LEVEL C: the hydrographic maps for the total area of the Siret river basin.

Data quality is analysed considering the consistency, representatively, homogeneity and the volume of information within the range of observation. The maximum flow series available cover a sufficient period of time for the application of the methods of statistical analysis (generally 40-60 years, but they have been taken into account as well as the data series with an observation period less than 30 years).

Values that do not fit into the general behavior of the data series can be found in the Bistrita river basin at the hydrometrical stations, Luminis (Iapa River), Sabasa (Sabasa River), the Carlibaba River (Bistrita River), Bacau (Barnat River) and Magura (Negel River). The relatively frequent incidence of floods for Bistrita river basin can be identified in the year: 1970, 1991, 2005 and 2010. The average quantity of precipitation is 690 mm (the most humid months are specific to the summer and the drier ones are specific to winter). Sometimes, at the end of spring, floods from melting snow may occur.

3.1. Hydraulic modelling - maps of floodability

The role of hydraulic models is to transpose the liquid flow from the key sections in levels and at the required probabilities. This way, the boundaries of flood hazard mapping are drawn up. Hydraulic modelling is based on the use of ISIS software modelling of hydrodynamic motion (unsteady regime). Like any other modelling software (MIKE, HEC-RAS, SOBEK, DAMBRK and so on), ISIS is a system for modelling, specialized in issues of flood risk management, which has brought along with it an advanced degree of complexity and flexibility, in relation to the diversity of the situations that is to be modelled. It offers analysis and prediction tools for realizing hazard and risk maps that are used to develop management strategies at the river basin level or in the design of effective development schemes.

The ISIS program was selected as the optimal method of modelling, because the 1D and 2D models are based on numerical solution of the unsteady movement with the following components: ISIS-Professional-1D modelling approach, and in more complex areas, detailing is done by coupling 1D with 2D model. In addition to these functions, the ISIS program is integrated with ISIS Mapper and DSF which, are useful tools in the flood management system and result to a considerable increase in the performance and functionality level; ISIS-2D was developed by Halcrow for the 2D modelling with variability in time integration of the water blade, and it has outstanding capabilities in the propagation of surface water flow on slopes and flash flooding.

In order to obtain a good modelling, the 1D models are achieved at first, for all analysed rivers (in this case, we are talking about the lower sector of the Bistrita), and then, it follows the 2D detailing in the focus areas (by coupling the 2D model with 1D). The project used the ISIS 3.5. in which the longitudinal profiles, cross-sections, flows, levels and speeds hydrographs have been loaded in order to obtain the result. The main deliverable part of the project consists of the realization of the flooding map areas for different probabilities of occurrence, that is, the risk mapping component as defined in *article 2, annex 2, from H.G 447/2003*, but without an indication of the potential human and material damage. The elaboration of the flood hazard maps is the first step in determining the necessary methods for risk management and the implementation of appropriate measures in reducing the risk and the consequences thereof.

The following steps are identified in building the ISIS model: 1. Creation of the completed model, including the topobatimetric elevation in the riverbed; 2. Identifying obstacles that can change the water level (weirs, dams, sluices and so on) and running the model for generating initial conditions and for its stabilization; 3. The insertion of other structures such as; bridges, decks and culverts; 4. Checking the operation of the model at low flow rates, in order to be able to make a comparison with the observed data from the topobatimetric measurements; 5. Creation of Digital Terrain Model (DTM).

In order to achieve the coupling of the ISIS

2D and ISIS 1D models, the following stages are completed: 1. Assembling all data available for the topographical land surface (topobatimetric elevations); 2. Assembling the GIS data sets available (data in vector format, ortophotoplans, raster images, and so on); 3. The delimitation of the area of interest; Determine the 2D extension area; 4. Identification of the locations for the boundary conditions; Identification of inactive areas in the 2D field (for example, terrain elevations); 5. Identification of the elements which can be 1D modelled and realizing this, by setting the grid mesh, orientation and size of the cell; 6. Generating the grid cell levels close to the dyke, reservoir and other types of units, which are not included in the data DEM/DTM; 7. Analysis of 2D network generated by ISIS-2D; 8. Assigning appropriate values for roughness; 9. Determination of the time step at which to make the simulation.

Topographic data sets required for the ISIS model must provide optimal details for an accurate representation of the riverbed, the structures and the major riverbed in the hydrodynamic models. They can be obtained from the aerial measurements of the river bed (DTM) and through the topobatimetry of the minor riverbed. The modelling of the major riverbed is done based on the data extracted from the DTM, using a resolution that ensures a reasonable calculation time. In the case of 1D model, obtained on the basis of the DTM 5 m resolution, it has opted for the 20 m resolution resampling. Resampling for 2D models was done for a resolution of about 2 m to 5 m (without affecting the accuracy of the results). The topobatimetric data necessary for tracing the transverse profiles have been converted to the format accepted by ISIS modelling, that is, type *.txt* files and files in AutoCAD format. The transverse structures conducted in AutoCAD are extremely accurate and correctly fill all the information necessary for retrieving the dams, flood gates, bridges, and even transversal profiles in the ISIS program.

For the schematization of the model, a series of rules should be respected: 1. The methodology must be chosen in such a way that the level of accuracy should be the one required, capable of operating with very good precision both in small waters, and when the riverbed overflows or when recording top level of the water in the major riverbed; 2. The transverse profiles made in the minor riverbed must be analysed very carefully, so that the embankment that is located above the quotas of the major riverbed are represented as correctly as possible; 3. The structures must be modelled at an accessible level, under the logic rules of the ISIS modelling program and the hydraulic operation system must be as understandable as possible, while taking into account the available data Romanescu et al., 2018a,b,c) (Table 3).

Table 3. Types of hydro-technical structure – key points

Node	East	North	Type of structure
BS_L04.S28	583047	602016	BRIDGE unit
BS_L04.S27	584303	601472	BRIDGE unit
BS_L04.S24	585619	599979	BRIDGE unit
BS_L04.S23	585539	599731	BRIDGE unit
BS_L04.S22	585547	599698	BRIDGE unit
BS_L04.S21	586072	599484	BRIDGE unit
BS_L04.S20	586391	599775	BRIDGE unit
BS_L04.S19	587023	599755	BRIDGE unit
BS_L04.S13	590813	602639	BRIDGE unit
BS_L04.S11a	592623	603626	QHCONTROL
BS_L04.S10	593006	603930	BRIDGE unit
BS_L03.S31	593150	604106	BRIDGE unit
BS_L03.S27u	595685	605138	QHCONTROL
BS_L03.S26	596433	605219	BRIDGE unit
BS_L03.S20a	602347	604483	QHCONTROL
BS_L03.S17	604039	603668	BRIDGE unit
BS_L03.S16u	604741	602856	QHCONTROL
BS_L03.S00	614385	593619	BRIDGE unit
BS_L02.S20	624372	583445	BRIDGE unit
BS_L02.S14	628762	580337	BRIDGE unit
BS_L02.S10u	631421	578322	QHCONTROL
BS_L02.S06	633590	576816	BRIDGE unit
BS_L02.S05	633741	576763	BRIDGE unit
BS_L02.S01	636823	576912	QHCONTROL
BS_L01.S20a	644494	571868	QHCONTROL
BS_L01.S18	646123	570713	BRIDGE unit
BS_L01.S11	647545	565668	QHCONTROL
BS_L01.S09a	647996	563883	RNWEIR unit
BS_L01.S09a	647996	563883	QHCONTROL
BS_L01.S05	649433	560095	BRIDGE unit

In the ISIS modelling program, the coefficients of roughness are used. The mean value of roughness in the main channel area must be different from that used in the major riverbed area. The values are estimated by taking into consideration the vegetation, the composition of the riverbed and meanders (Li et al., 2015).

For better accuracy, the roughness values are determined on the basis of the information obtained in the field (visual inspections, photos), plus the experience of adapting to local conditions of the classification of roughness values. The most common values of roughness of the riverbed are 0.035 in the minor riverbed and 0.05 in the major riverbed. In order to calibrate the models, the reproduction of the flood waves from 2005 was taken into account when the historic flows registered for all rivers in Romania was recorded (4,650 m^3/s at Lungoci) (Romanescu & Nistor, 2011). The records obtained from the hydrometrical stations were used for both input and verification data. For the comparison of the results, the main course was considered. The calibration process can be improved through detailing of the data sets used, applying adjustments also for the fixed parameters (relative length of the route between key sections and so on) but also, by analysing some additional remarkable events (flash floods in 2008, 2010) (Romanescu, 2009; Romanescu & Stoleriu, 2013; Romanescu et al., 2018a,b,c) (Fig. 3).

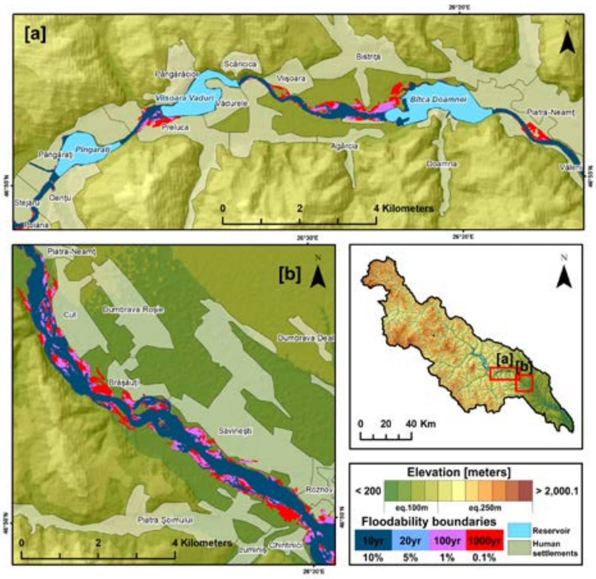

Figure 3. Floodability boundaries probabilities by 10% (10yr), 5% (20yr), 1% (100yr) and 0.1% (1,000yr) downstream Izvoru Muntelui Reservoir. River segment: [a] Stejaru – Piatra Neamt; [b] Piatra Neamt – Roznov.

The flash flood waves have been established as computing scenarios with peak flow rates equal to the maximum annual flow, having the probability 10%, 5%, 1% and 0.1% (Table 4). The peak flows errors (< 15%) are below to the acceptable limits in order to achieve the floodability study maps. The models are made by using the existing database, but some improvements can be added in the following areas of interest: 1. Cross-sections, major riverbed modelling; 2. The boundary conditions in the downstream node (depending on curve rates); 3. Transverse structures (dams/thresholds, bridges), detailing the information where the hydraulic effect is significant; 4. Entries in the model, by detailing in particular those sides; 5. Additional recent events can be integrated in the model calibration process; 6. Retrieving the new changes and reviewing the flooding maps for a better result.

Realization of the flood hazard maps has been made through the ISIS-Mapper application. With ISIS Mapper, the floodable areas have been generated in the case of the calibration event (2005), computing scenarios of 10%, 5%, 1% and 0.1% probabilities respectively, for both expansion limits and water depth (Table 4; Fig. 3, 4, 5 and 6).

Hazard maps of level B are made for the downstream sector of the Izvoru Muntelui Reservoir, up to the entrance into the city of Bacau (Fig. 3). The level *A* maps are made for the river sector next to the city of Bacau (Fig. 4). Floodability maps were also realized for the superior sector of the Bistrita River (Fig. 5) and upstream Izvoru Muntelui Reservoir (Fig. 6).

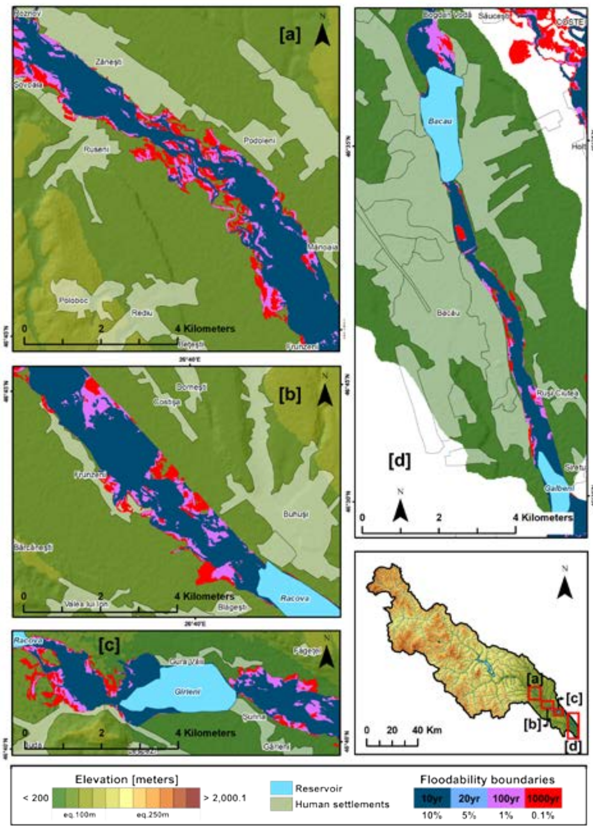

Figure 4. Floodability boundaries probabilities by 10% (10yr), 5% (20yr), 1% (100yr) and 0.1% (1,000yr) in the lower area of Bistrita basin. River segment: [a] Roznov – Frunzeni; [b] Frunzeni – Racova Lake; [c] Racova Lake – Girleni Lake; [d] Bogdan Voda – Galbeni Lake.

In order to generate the limits of expansion within the flood hazard maps, the following steps were taken: 1. Extracting maximum levels in cross-sections; 2. Define the river through a central line, used by ISIS-Mapper application to generate perpendicular cross-sections; 3. Polygon *shp.* generation for the reservoir units of the ISIS model; 4. Adjustments to the cross sections in order to obtain complete coverage of the riverbed; 5. Running ISIS-Mapper to generate the surface and depth of water using intersection or DTM quotas difference, and to generate polygons for extending the limits of the floods (as ArcView *shp.* files and *grid* files).

Application of mathematical modelling may not compensate for any deficiencies as regards the existence of the database or its insufficiency (Strupczewski et al., 2006). Any uncertainty in the input level becomes a source of errors in the final result. It is very important that the data are used in the implementation model, for it to be well analysed. The flood hazard maps are probable and may show accuracy only when they are constantly updated. The topographic data must also be corrected on a regular basis because, after every flood, the riverbed surface changes (both vertically and horizontally).

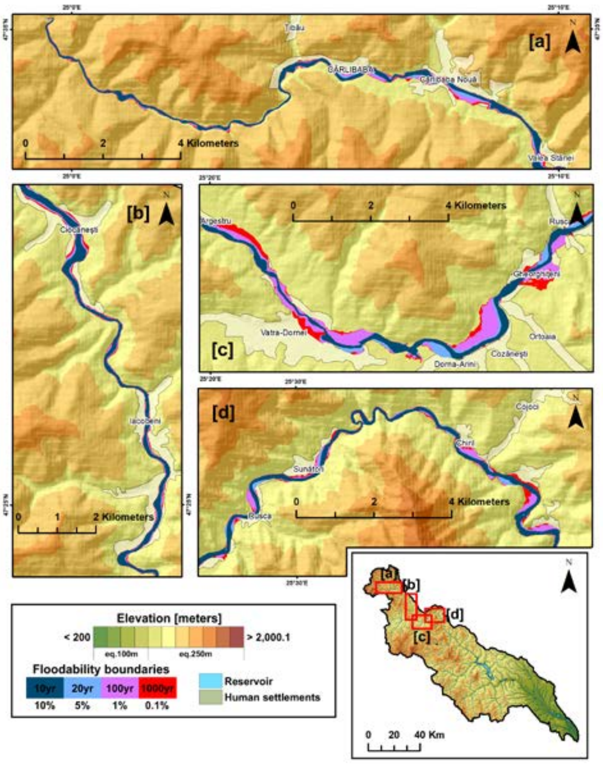

Figure 5. Floodability boundaries probabilities by 10% (10yr), 5% (20yr), 1% (100yr) and 0.1% (1,000yr) in the upper area of Bistrita basin. River segment: [a] Carlibaba – Valea Stanei; [b] Ciocanesti – Iacobeni; [c] Argestru – Rusca; [d] Rusca – Chiril.

Hydrological data analysis and the hydraulic modelling have led to obtaining the flooding boundaries with insurance of 10% (10 years), 5% (20 years), 1% (100 years) and 0.1% (1000 years) for upstream area of the Izvoru Muntelui Reservoir and lower sector of the Bistrita wathershed (Table 5), and for downstream area of the Izvoru Muntelui Reservoir up to the confluence with the Siret River (Table 6). The upper sector, modelled in hard rocks with relatively narrow valley is the area affected by flooding on small areas. The lower sector, with large valley, modelled in the loose rocks, is flooded in broad areas and may have an increased risk because of some important cities nearby: Bacau, Piatra Neamt, Bicaz, and so on.

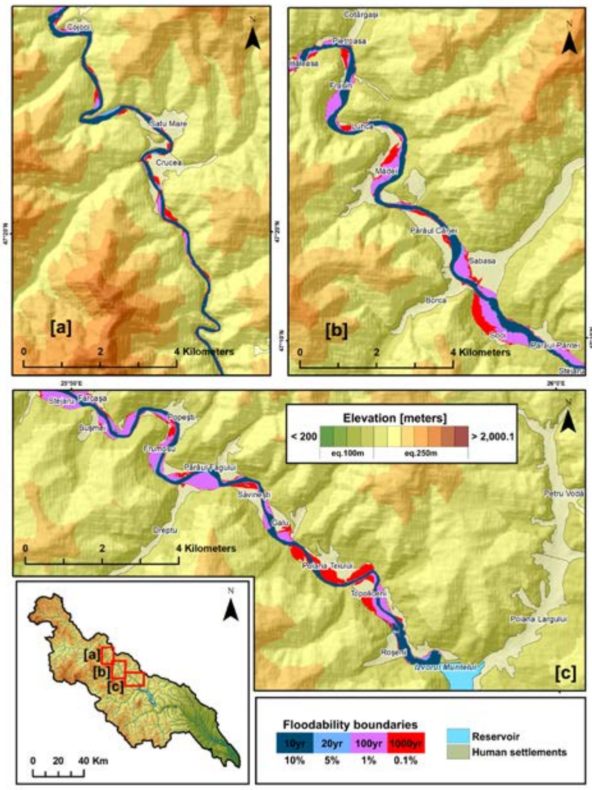

Figure 6. Floodability boundaries probabilities by 10% (10yr), 5% (20yr), 1% (100yr) and 0.1% (1,000yr) upstream Izvoru Muntelui Reservoir. River segment: [a] Cojoci – Crucea; [b] Pietroasa – Paraul Pintei; [c] Farcasa – Poiana Teiului.

4. CONCLUSIONS

The final products are obtained with advanced technology and are very useful, whereas, at present, the risk management for flooding is based on decisions that need complex and detailed information. Currently, it has a detailed and complex system that allows the adequate identification of critical areas for the flood hazard through integration with high performance computing technologies. ISIS hydraulic modelling tools and the flood maps resulting from their use are recognized to be at the top of the industry.

Flood risk management is necessary because the Bistrita River is prone to more and more floodability events, many of them with catastrophic character. The most affected areas are middle and lower sector of the Bistrita wathershed, where the most populated cities are located: Piatra Neamt, Bicaz, and Bacau. The main hydrological hazard is represented by the breaking of the Bicaz Dam (Izvoru Muntelui Reservoir), which can lead to total

Table 4. Flow rates calculation scenarios simulated on the check point Frunzeni (Bistrita)

River Model	Hydrometrical station	Calculation scenario	Comparison of peak flows (m^3/s)		
			Target Value	Model Value	Difference
Bistrita_v7.dat	Frunzeni	10%	719	751	32
		5%	948	991	43
		1%	1457	1453	-4
		0.1%	2277	2209	-68

Table 5. The surface of the floodability boundaries upstream Izvoru Muntelui Reservoir

Probabilities %	0.1	1	5	10
Surface km²	188.72	111.15	74.29	68.67

Table 6. The surface of the floodability boundaries downstream Izvoru Muntelui Reservoir

Probabilities %	0.1	1	5	10
Surface km²	540.45	444.89	337.19	289.33

destruction in the cities of Bicaz and Piatra Neamt and partially of Bacau. To eliminate possible shortcomings with regard to the construction within the floodplain, periodic updates of the maps of floodability (hydrologic risk), with studies from 6 to 6 years are required. The training and transfer of know-how and the developed skills of the personnel must be done regularly, in order to maintain and update the current products. The level of accuracy will reach very high odds and the error sources will be more limited in time.

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