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DOCTORAL THESIS

BISTRITA RIVER HYDROLOGICAL REGIME ANALYSIS CONSIDERING THE EXISTENCE OF THE HYDROPOWER PROJECTS

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1. INTRODUCTION

The complex influences of human society on the hydrographic networks have lately gained a particular momentum because of the development of economic activities. Very often even if the hydrotechnical works were meant to bring benefits, they had many negative side effects, and sometimes disastrous.

The anthropogenic activities have an important impact on the environment due to a complex development of water courses (in this case - Bistrița River Basin) for primordial economic interests, namely: drinking water supply, irrigation, industrial and prevention and defence against floods, gravel pits, resources exploitation C.E.S. (soil erosion), hydropower, etc.

The present doctoral thesis aims to be challenging on the study, in terms of the hydrological regime, of the Bistrita River Basin. The research focuses on the most important aspects and does not detail the myriad hydrological issues. The meteorological and hydrological data (up to the year 2014) collected from various institutions: National Administration of Meteorology, National Institute of Hydrology, and Water Management Administration, Siret Water Basin Administration, SC Hidroelectrica SA. Observations in the field aimed to link, validate the data, and completed by photographic images in order to have a clearer image of the terrain.

In addition to all this it has been achieved a number of thematic maps by means of modern techniques of ArcGIS type. The maps display in a suggestive manner issues relating to the elements that make up the natural setting in which it forms and evolves water resources from the Bistriţa River basin (relief, geology, soils, vegetation, land use, etc.).

2. DATABASE AND METHODOLOGY

The database includes hydrological data (maximum flow, medium liquid, and mud in suspension) from hydrometrical stations from the Bistrița River Basin, climatic data (rainfall, annual, and monthly temperatures) from pluviometric and meteorological stations in the area. New information related to the degree of silting of the reservoirs from Bistrița, and land use were analysed (the international database CORINE Land Cover and cartographicmaterials – ortophotoplans 2006; topographic maps 1:25000, edition '80; digital terrain model for Romania, SRTM90).

Geological, geomorphologic, and soil data etc. were taken from the literature or from personal observations resulting from field trips. Cartographic base conforms to the maps in the scale 1:25.000 and ortophotoplans developed by ANCPI Romania. The cartographic materials have also been taken from http://srtm.csi.cgiar.org/website (CGIAR CHALLENGE, 2008) SRTM 90 m (Digital Elevation Data). Data on the degree of afforestation is taken from the Corine Land Cover 2006 prepared by the Ministry of the Environment and Sustainable Development (http://www.eea.europa.eu/data-and-maps/data).

The database has been processed both graphically and statistically for the achievement of the objectives of the work. The software used to process graphics and database for statistical analysis are Microsoft Excel (XLstat) and Sigmaplot, and maps were constructed using ArcGIS software 10.3.

Methodology of classical and contemporary work includes:

- Surveys in areas with a high level of flood occurring;
- Statistical interpretation of numerical, hydrological and climate data in order to identify some correlations and obtain specific opportunities of forecasting, etc.;
- Terrain investigation to validate data;
- Mapping (through software) of the climatic parameters with impact on the hydrological regime of the rivers;
- Data processing, starting from the digital terrain Model, to emphasise a number of morphometric parameters of water basins (area, length, slope of the basin, of river network, different hydrographic network density, form factors, with the development of surface and subsurface flow routing etc.);
- Testing, validation and application of mathematical models for forecasting.

3. RESULTS

3.1. Runoff regime (average, maximum, and minimum).

In order to make an analysis of the runoff regime were taken into account more hydrometrical stations, both on the main course and tributaries. The main source of runoff water supply is precipitation and snow cover. Groundwater bring an intake of about 30 percent, even more according to some other studies (Lăzărescu, Panait, 1958; Băloi, 1971; Amăriucăi, 1975; Diaconu et al., 1982; Olariu, 1992).

After a monthly analysis of runoff, the result is that the winter months register the lowest values. In terms of percentage, in the winter months (December-February) runs between 8.4% of the annual volume at hydrometric station Poiana Stampei and 23.0% at stations in Bacau (Barnat River). In December, the runoff was between 3.3% and 6.8%; 2.5% in January and 6.4 percent and in February by 2.4 percent and 6.2 percent. Spring is the richest season, from this point of view, having a total of 32.5-50.0%. Summer runoff retain is also rich (28.4% of 24.5-annual volume) due to the large quantities of rain falling this season. Since early august the monthly runoff decreases (-11.8%) and 6.9 this drop continues throughout the fall: September (6.8-7.9%), October (3.8-6.8%) and November (3.4-6%). In general, one can speak of rich runoff, when the specific flow rates are higher than 10 $l/sec/km^2$.

Analysing the runoff for a longer period of time we can identify years with average runoff (1956, 1960, 1965, 1967, 1976, 1985, 1993, 2000, 2004, 2006 etc.), years with rich runoff – rainy years (1955, 1969, 1970, 1972, 1973, 1975, 1978, 1979, 1981, 1984, 1988, 1991, 1995, 2006, 2008, 2010) and years with poor runoff – droughty years (1950, 1952, 1963, 1968, 1987, 1990, 1994, 1995, 2003).

The hydrotechnical works from the main course of Bistrita River and main tributaries aimed to alleviate flooding, to ensure the supply of water and electricity. Floods from 1970 could not be prevented since the spring rains have filled the riverbeds up to banks level and the reservoirs were full. In this case, the floods manifested as on an undeveloped river. The latest floods, from 1991, 2005, or 2010, occurred mostly on some tributaries. Flood waves were propagated on Bistrita River because some reservoirs have a high degree of silting, so they could not take up the excess water and the waves had devastating effects. In the case of watershed flow, small floods which occur are caused by the existence of conditions favouring local: anthropogenic deforestation, inappropriate works (bridges, dams, etc.), occupation of the minor riverbed due to economic objectives (sawmills, gravel and sand stations etc.) or houses etc.

For mitigation and actual warning of floods DESWAT program (installation of automated stations and flow tracking).

3.2. The hydrotechnical development of Bistrita River Basin and the impact on the aquatic ecosystem.

The large basin surface (4070 km² – in the middle and inferior sectors), the average flow 50.7 m³/s and maximum flow1080 m³/s, a fall of 372 m for 125 km distance and an average power potential of 1200 kw/km, make this sector perfect for a series of functionalities: energy producer, flow regulation, mitigation of floods, irrigation, water supply and recreation.

The construction of reservoirs is a major intervention in the natural hydrologic system because of the modifications that occur. Therefore, the water balance has great importance when analysing a reservoir.

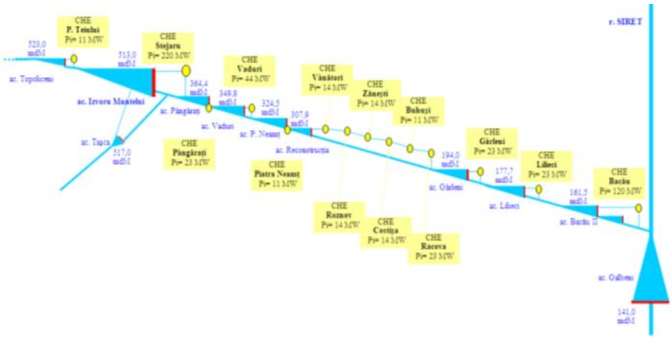


Fig. 1 Bistrita River Hydropower development (source Siret Water Basin Administration, 2015)

The cascade of reservoirs on Bistrita River influences the level regime in this sector because of the hydropower plants. Thus, determination of all components of the hydrological balance implies a very laborious and difficult activity.

There were taken into account the values recorded at the hydrometric stations from the middle and lower sectors of Bistrita River and the evaporimetric station Ruginesti in order to calculate the hydrological balance of Izvoru Muntelui Reservoir. Relief, slope, vegetation, land use etc. directly influence the average runoff, as part of the water balance.

Affluent flows (Qaffluent) used are: flows from hydrometrical stations from the basin ; deffluent flows of the reservoir ; flows from adducts ; interbasin corresponding flow areas ; flow of precipitation that fell on the reservoir surface and flow corresponding to the quantity of water stored in the snow and ice.

Deffluente flows (Qdeffluent) used are: flows corresponding to derivations; flows corresponding to conducts; turbine flows; evacuated flows; flows corresponding to evaporation from the reservoir surface .

For calculating the water balance for **Izvoru Muntelui** we have the equation Qaffluent = Qdeffluent ± W/T, expressed in m³/s.

Table 1 IZVORUL ALB hydrometrical station

MONTH	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
PRECIPITAȚION	42,5	29,3	32,3	33,4	126,4	276	100,5	64,8	45,5	59,9	35,2	50,1
WATER VOLUME (mil.m³)	1,339	0,923	1,017	1,052	3,982	8,694	3,166	2,041	1,433	1,887	1,109	1,578
CORESPONDENT FLOWS (m³/s)	0,500	0,382	0,380	0,406	1,487	3,354	1,182	0,762	0,553	0,704	0,428	0,589

Table 2 RUGINESTI evaporimetric station

MONTH	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
EVAPORAȚION					40,4	40,7	57,5	61,4	30,2	10,6	21,2	
WATER VOLUME (mil.m³)					1,273	1,282	1,811	1,934	0,951	0,334	0,668	
CORESPONDENT FLOWS (m³/s)					0,475	0,495	0,676	0,722	0,367	0,125	0,258	

Table 3 Qhydrometrical stations + Qprecipitation = Qaffluent

WATER FLOWS AFFLUENTE	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
R **Bistrița** HS **Frumosu**	31,0	18,3	37,3	55,6	82,6	93,2	134,0	65,3	42,8	33,3	39,2	58,7
R **Bistricioara** HS **Bistricioara**	4,51	3,46	7,45	11,1	13,7	17,2	24,7	17,5	7,31	5,24	5,50	12,1
R **Schit** HS **Ceahlău**	0,351	0,426	0,488	0,447	1,10	2,54	2,50	1,49	0,794	0,436	0,426	0,802
R **Bolatău** HS **P Largului**	0,169	0,156	0,615	0,374	0,837	0,826	1,35	0,724	0,313	0,293	0,249	0,592
R **Bicaz** HS **Tașca**	3,15	2,35	5,69	7,14	9,78	16,4	21,7	8,93	4,79	4,02	3,69	8,24

Q DIN PRECIPITAȚION ON THE SURFACE OF RESERVOIR	0,500	0,382	0,380	0,406	1,49	3,35	1,18	0,762	0,553	0,704	0,428	0,589
TOTAL Q AFFLUENT(m³/s)	**39,7**	**25,1**	**51,9**	**75,1**	**109,5**	**133,5**	**185,4**	**94,7**	**56,6**	**44,0**	**49,5**	**81,0**

Table 4 Qturbine + Qevaporation= Qdeffluent

WATER FLOWS DEFFLUENTE	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Q TURBINE	23,3	33,8	22,7	24,8	22,8	79,4	206,2	124,0	53,8	33,3	61,7	81,8
Q EVACUATED (BOTTOM EMPTYIND +EVACUATED)			0,160			16,0	71,7	19,7	0,183	0,113		
Q EVAPORATION ON WATER SURFACE					0,475	0,495	0,676	0,722	0,367	0,125	0,258	
TOTAL Q DEFFLUENT	23,3	33,8	22,9	24,8	23,2	95,9	278,6	144,4	54,4	33,5	61,9	81,8

Table 5 WATER BALANCE - Izvoru Muntelui

WATER BALANCE	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Q DEFFLUENT	23,3	33,8	22,7	24,8	22,8	79,4	206,2	124,0	53,8	33,3	61,7	81,8
W / T	14,36	-9,3	27,6	45,7	82,1	44,54	-12,3	-24,5	3,53	9,02	-13,1	2,09
Q AFFLUENT = Q DEFLUENT(±W/T m³/s)	37,64	24,44	50,3	70,5	104,9	124,0	193,9	99,5	57,3	42,3	48,6	83,90
Q AFFLUENT DETERMINED AS SUM Q HS = Q	39,18	24,69	51,54	74,66	108,02	130,17	184,25	93,94	56,01	43,29	49,07	80,43
	3,93	1,03	2,51	5,57	2,91	4,77	-5,23	-5,90	-2,39	2,28	0,88	-4,31
E =(Q4-Q3) / Q4 *100	23,3	33,8	22,7	24,8	22,8	79,4	206,2	124,0	53,8	33,3	61,7	81,8

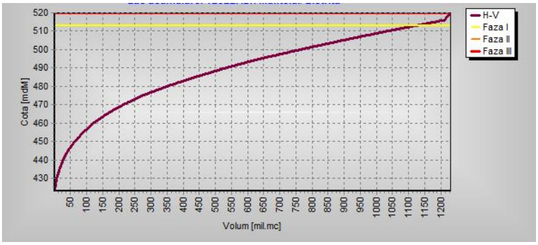


Fig. 2 Volumetric curve of IZVORU MUNTELUI Reservoir

3.3. Degree of silting for the reservoirs

When a forecast of silting (taking into account the existing measurements and solid flow transported from Bistrita River) Izvoru Muntelui Reservoir is not in danger of silting in the nest millennia. The silting rate cannot be higher than 200000 m³/year.

Besides the role of regulating the flow regime, the reservoirs have a very important role in mitigating flood waves. Of all the reservoirs on Bistrita River, Izvoru Muntelui is the only one that can take over 1% assurance flash floods, respectively 360 mln. m^3.

Table 6 Characteristics of the reservoirs on Bistrița River Basin

No	Reservoir	Year of Commissioning	Dam hight (m)	The initial volume at NNR (mln m³)	Current volume at NNR (mln m³)	Upstream basin area (km²)	Degree of silting (%)
1	Poiana Teiului – Topoliceni	2004	15,5	0,7	0,7	2886	0
2	Izvoru Muntelui	1960	127	1230	1122	4022	8,80
3	Pangarati	1964	28	6,00	2,01	5142	66,5
4	Vaduri	1966	27	5,60	2,39	5213	57,3
5	Batca Doamnei	1963	22,3	10,0	6,50	5290	35,0
6	Reconstructia	1963	8,15	0,25	0,23	5403	8,00
7	Racova	1965	20	4,37	empty	6580	-
8	Garleni	1965	19	5,10	2,30	6758	54,9
9	Lilieci	1966	19	7,40	5,40	6775	27,0
10	Bacau II	1966	18	4,60	4,42	6814	3,90
11	Tasca	1980	20	0,10	0,09	512	0,01

NNR=normal level of retention.

After analysing the degree of reservoir silting in the basin we concluded that most of the reservoirs are silted even over 50%, which means that the supplementary flows cannot be totally stored and severe floods with devastating effects may manifest. Exception to this rule are Topoliceni, Tasca, Izvoru Muntelui and Reconstruc Reservoirs (the sediment load in the reservoirs has been removed by successive unsilting).

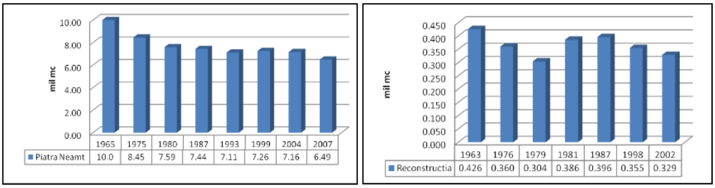


Fig. 3 Piatra Neamt Reservoir volume during 1965-2007 and Reconstructia Reservoir volume during 1963-2002

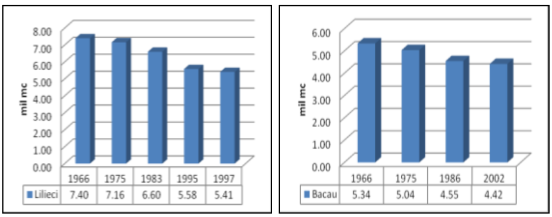


Fig. 4 Lilieci and Bacau II Reservoirs volume during 1966-1997 and respectively 1966-2002

3.4. Water quality

The most important sources of pollution in Bistrita River basin are located in urban areas or around: Vatra Dornei, Bicaz, Piatra Neamt, Savinesti-Roznov, Buhusi and Bacau. Pollutant load from the industrial water is one of the largest and the most harmful types of pollution.

Lately, most operators have started to modernize the equipment in order to reduce pollutant characteristics of wastewater. Currently several programs are ongoing for developing and modernization of centralized sewerage systems and wastewater system.

In terms of water quality Bistrita River is devided into two sections: the upper stream, where water parameters are fully good class quality (class I quality); and the middle and lower stream, where the water has an average quality.

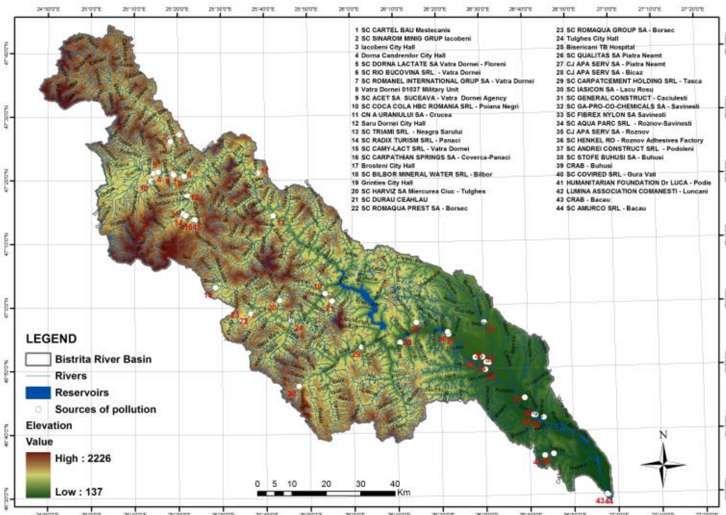


Fig. 5 Sources of pollution in Bistrita River basin

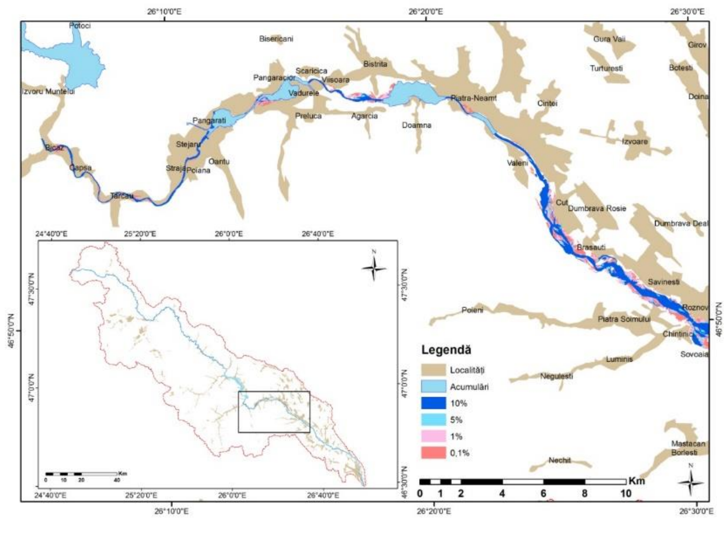
3.5. Hydrological modelling. Flooding maps.

In order to prevent or mitigate the effects of floods and to enable us to comply with the national strategy and European legislation is necessary to achieve and update natural hazard and risk maps.

The database related to Bistrita River basin has been harnessed by making flooding maps for the areas with priority interest.

Certain elements were needed for creating the flooding maps, such as: flows, climatic data (temperatures and precipitations), computing hydrographs, a hydrodynamic model, and the levels during floods. For the hydrodynamic model first were prepared: topographic elevations, hydrographic measurements, aerial and topographic measurements for the hydrotechnical constructions.

This chapter analysed a very important subject for European policy in the field of water management (Directive flooding/2007). The final products are obtained with advanced technologies and are very useful as flood risk, now, is based on very complex, detailed, and accurate information.



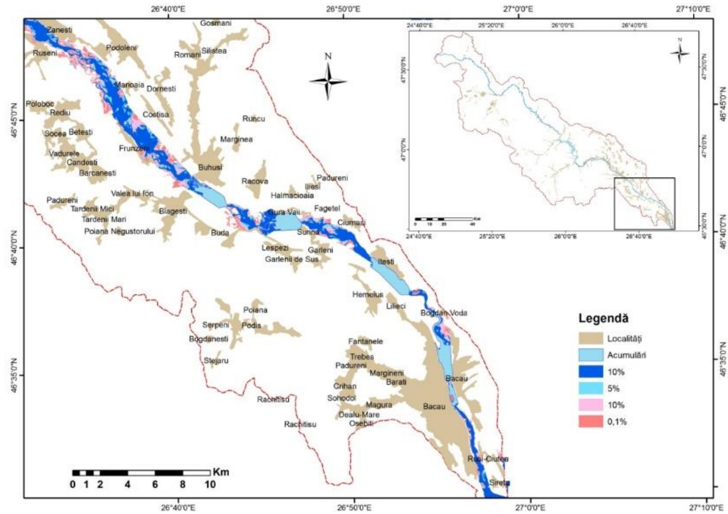
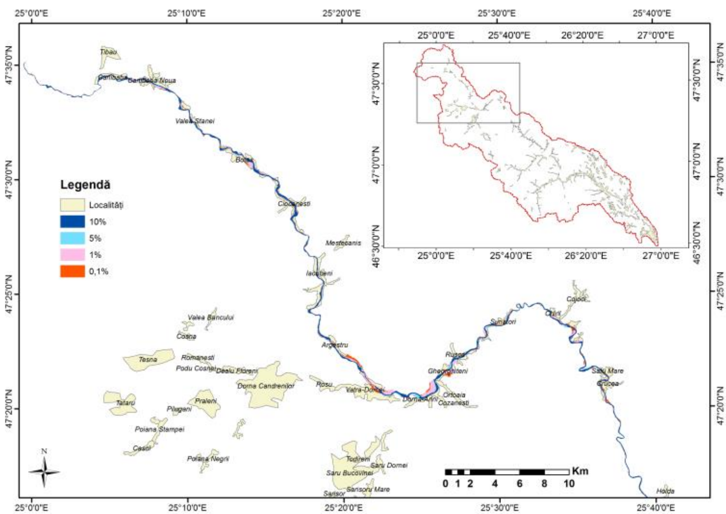


Fig. 7 Flooding maps with 10%, 5%, 1% and 0.1% assurance for the sector downstream Izvoru Muntelui Reservoir



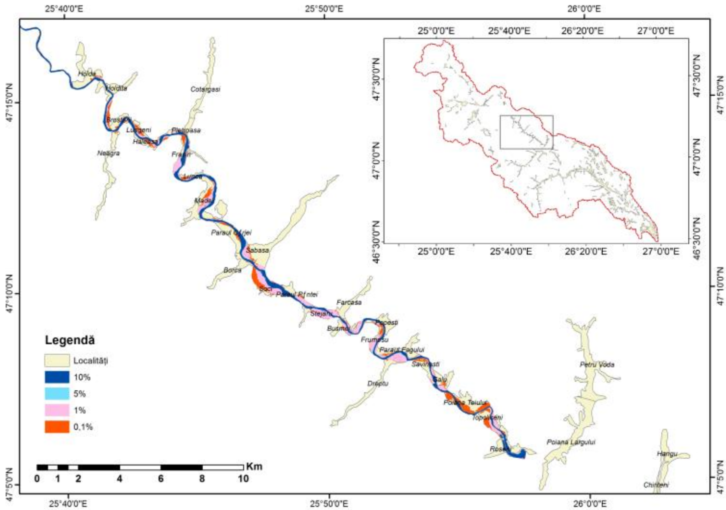


Fig. 8 Flooding maps with 10%, 5%, 1% and 0.1% assurance for the sector upstream Izvoru Muntelui Reservoir

4. CONCLUSION

Bistrita River is the longest tributary of Siret, with a length of 283 km, an area of 7039 km² and 193 tributaries of its own. The geographical location of Bistrita River basin is of great importance in determining its hydrological regime, as it has an influence on all the factors that depend on it: climatic, geological, morphological, vegetation, soil, land use, etc.

Bistrita River is located in the middle of the temperate continental climate with oceanic influences.

The current course of Bistrita began to emerge towards the end of presarmatian period, and in the middle of sarmatian Bistrita's course was comparable to the current one.

Bistrita River passes through two major units: Carpathian Orogen unit, from the Bistrita's springs to the locality Racova; and the Platform unit, from Racova locality to the confluence with the Siret River.

There can be identified tree large sectors of relief: the mountainous sector (Oriental Carpathians) from Bistrita's springs to Piatra Neamt locality; the subcarpathian sector from Piatra Neamt locality to Racova locality; and the tableland sector, from Racova locality to the confluence with Siret River. The high terraces are well represented, and the meadow steps reach large widths.

The diversity of physical-geographical factors (relief, climate, soils) favoured the development of complex vegetation (alpine, sub-alpine, spruce forest, mixed beech-coniferous and beech).

The most significant floods from Bistrita River basin registered in 1970, 1991, 2005, and 2010.

After 1950, the Bistrita hydropower development started to shape. For the whole cascade of reservoirs on the Bistrita River were constructed 10 dams, 12 hydropower plants, and 61 km of channel. In order to transform this sector sometimes people and localities had to be moved.

The construction of reservoirs represented an intervention in the natural hydrologic system by changing some of its characteristics. Therefore calculating the water balance is of great importance because it represents the balance between the total affluent flows (A) and total deffluent flows (B) and, of course, the variation of the water volume in the reservoir (W/T). The reservoirs have a significant role because they can mitigate the flood wave downstream.

The reservoirs on Bistrita River have a degree of silting over more than 50%, which means that supplementary flows cannot be stored completely and may manifest devastating floods. The Topoliceni, Tasca (on Bicaz River), Izvoru Muntelui and Reconstructia (the alluvial deposit has been removed by successive unsilting) are the exceptions.

The main sources of pollution in Bistrita River Basin are from the traditional human activities and from recent industry. The water quality is first class on the upper stream and IInd, IIIrd, IVth, Vth class on the middle and inferior course.

The HYDRAULIC MODELLING chapter – flooding maps analysed a very important and up to date subject. The database was analysed and the flooding maps for Bistrita River have been achieved by using ISIS modelling program.

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