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NEW SOLUTIONS IN RECALIBRATION OF RIVER BEDS IN NATURAL CONDITIONS, CONFRONTED WITH REPEATED FLOODS

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Abstract

Due to irrational exploitation of water reserves from some hydropower systems and due to improper maintenance of the natural river beds, in present days, in conditions of abundant rainfall, the whole area into river vicinity are in a real danger. The present paper is dedicated to estimate the real capacity of transport of natural riverbeds in permanent correspondence with the zone reality during and after repeated floods. A numerical model based on experimental measured local data is elaborated. In these conditions in 2005, 2010 and 2012 in the Siret basin, on Bistrita and Cracau rivers area, nine floods considered major were mentioned, followed by human victims, lost animals, and huge terrains under water for more than five weeks. First is presented an actual documentation concerning the situation of functioning, producing, transport and exploitation of hydro systems from the affected areas, based on local experimental measurements. A new numerical modeling of the free surface water flows is realized, taking into account the possibility of permanent changing of lateral surfaces (river beds) during floods, due erosion and sediment transport. It must be considered that during the floods may appear also zones with uncontrolled deposition of the moved and transported sediments. Finally, an optimum management of the flow rate on short and medium term, to assure the environmental protection of the affected areas and some conclusions are mentioned.

Keywords: *environmental protection, measurements, numerical modeling, repeated floods, sediments transport*

Introduction

In Romania, in the past 20-25 years was no complex plan for ecological and energetic rehabilitation for riverbeds, channels, and their vicinity realized. Considering the last decade, for the analyzed area (Siret basin) some places, more or less the same, are confronted with repeated floods. In 2005, 2010, 2015, and even 2017 twelve floods have been registered, nine of them considered critical. Moreover, in time, constant modifications of the riverbeds are recorded. Punctual erosions, followed by uncontrolled of sediments deposits elsewhere, coastal slides, have turned those zones in areas at risk (Nistreanu & Nistreanu 1999).

The EU laws concerning environmental protection impose that after every special hydrological event (for floods are dedicated four paragraphs) a rehabilitation of the entire affected area should be realized. If not, secondary phenomena appear, harder to be controlled. In time, without a management plan, for short or medium term, as to assure optimal ecological and safety energetic power conditions, the entire environment is affected.

There are places near the analyzed area where meander phenomena, sediment deposits, or uncontrolled coastal erosion appear, which in time lead to landslides, followed by the roads, houses, and agricultural terrains destruction. Years 2005 and 2010 are considered to have values way over the annual average from a hydrologic point of view, followed by floods, human, and animal losses, and severe material damages: houses, bridges, agricultural lands, and forests. In 2006, two severe ecological accidents have been recorded, due to cyanide leak from the settling basins in the water treatment plants. The phenome was followed by long-term environmental perturbations, with over-border pollution. It took approximately 2 months to reach the water, in the Danube Delta. The fact that most of the rivers from Moldavia area are part of the Siret hydrographic basin, reaching finally the Danube shouldn't be overlooked. At the current moment, the analysis of the natural rivers beds' transport capacity is only realized in areas with massive destruction and serious damages. Any technical research of the entire area, analyzing the phenomena in the whole basin, inter-connected, hasn't been carried out. Nowadays the international commitments impose complex analysis and arrangements for the entire hydrological basins.

The numerical model of sediment transport, consider the mass balance of the incoming and outgoing sediments. Consequently, considering the cross-sections, an action plan for tracking the changes of the geo-morphological basin can be estimated. It solves a recent problem, due to the actual conditions, regarding the flows in natural or critical regimes (high waters or lasting drought) in near vicinity of areas affected by repeated floods (Radulescu & Nistreanu 2004). By knowing the flow rate, by direct reading from the measurements sections, establishing the risks zones far away from the river borders will be possible.

Materials and Methods

Set in the Cracau – Bistrita Depression, the analyzed area, respectively Pangarati - Vaduri - Reconstructia is characterized by a continental climate. In terms of the climate, Neamt County has a specific climate, typical for plains and meadows. The main features of the microclimate are the following:

- The annual average temperature: 8.5°C,
- The average January temperature: - 4.5°C, due to the cold air coming from the north and east part to the lower areas,
- the average temperature in July is 20 ° C; can be explained by the possibility of hot, continental air circulation, especially from the South and East part,
- The relative humidity: 80%,
- The average annual rainfall amounts: 500 - 600 mm,
- The greater variety of precipitation is in July – November; the precipitations are higher than on the plateau, the annual average precipitation quantity in the hot season is 450 mm,
- The average wind speed at 10 m height above the ground: 3 m/s.

Bistrita River has springs that start in the southeastern part of the Rodna - Ineu mountain and the northern Călimani massif, gathering the water from the Dorna Depression. Bistrita was the first river entirely designed and engineered on the middle and lower course, and was built during 1951-1960. Bistrita is a tributary of the Siret, with an average flow rate of 45 m^3/s, over a length of 125 km, resulting in a vertical difference of 372 m and average energetic potential of 1200 kW/km. The dam of the Mountain Spring lake makes the multi-annual flow rate regularization. The minimum flow rate increases from 0,4 x Qm during the dry years to 0,7 x Qm in normal years. In Table 1 flow rate measurements carried out during a year in 5 measurement points are presented. The 12 hydropower plants on River Bistrita, downstream the Bicaz plant to its confluence with Siret River have a total installed capacity of 244 MW with and an energy production of 918 mil. KWh. The Mountain Spring Dam Catchments cover 4070 km^2, with a significant hydroelectric potential.

The analysis was accomplished based on in-situ measurements, taken from more than 60 places crossing the rivers Cracau, Bistrita, Siret, on both sides, during 2006-2016. The obtained hydro-chemical data prove the fact that the sediments are moved more than 45 km during a flood as the ones from the spring of 2005 (MacDougall 1993).

Table 1. The average flow rates measured values Q [m^3/s]

Sections / Q [m^3/s]	**SH Carnu**	**SH Pangarati**	**SH Vaduri**	**SH Piatra Neamt**	**SH Bacau**
X	27.96	33.25	33.52	33.85	37.99
XI	26.42	30.99	31.23	31.50	40.40
XII	21.48	25.36	25.57	25.81	33.83
I	17.96	21.25	21.38	21.59	28.49
II	18.13	21.46	21.63	21.85	27.05
III	32.11	38.41	38.77	39.19	44.61
IV	80.30	97.35	98.11	99.28	107.17
V	92.21	109.53	110.47	111.55	118.18
VI	73.15	87.65	88.41	89.34	96.22
VII	59.37	70.91	71.49	72.22	76.38
VIII	43.96	52.56	53.02	53.56	57.15
IX	33.10	39.51	39.85	40.29	41.87
Annual Average	43.85	52.35	52.79	53.34	59.11

An update of the flow characteristics of the interest sector was made considering a characteristic hydrologic period of 50 years (1960-2010). The values used in the study were based on the measurements made at Carnu, Pangarati, Vaduri, Neamt, and Bacau stations. These values were processed by the known statistical methods and insurance curves were drawn.

The calculated average annual flow of river Bistrita during the mentioned period is of 43.85 m^3/s at Izvorul Muntelui, 52.35 m^3/s at Vaduri, 53.34 m^3/s in Piatra Neamt, and 59.11 m^3/s at Bacau section. Lake Pangarati is the first lake from the analysis area, and provides partial regulation of the flow for the entire river basin. Lake Piatra Neamt is designed to assure the flow for the upstream turbine Q_I = 180 m^3/s, and for the downstream at Q_I = 84 m^3/s, where Q_I, is the installed flow rate.

The seasonal and annual adjustment possibilities of the Izvorul Muntelui accumulation leads to a redistribution of the water volumes, in different floods schemes, during spring and summer to a reduced leakage, at autumn and winter, for Pângăraţi Lake. The year 2005 was a year with large hydrologic variations from a month to another. Before July 12, due to the occurred floods, a bridge of large woods formed (inserts having even 60 cm in diameter). In these circumstances, in order to destroy the "bridge", the downstream power plants were stopped (Vaduri and Batca Doamnei). On August 12, another flood changed the main river flow channel (Figure 1). In Fig. 1 - the erosion and deposition of sediments can be seen, having as effect the main river course altering. On September 22 a new flood was registered. The water evacuated from the hydropower lakes, Fig. 1-b covered in large land areas downstream, Fig. 1-c. In Fig. 2 images from February 2017 and in April 2017 are shown. In these conditions, the average hydrological data, taken from the previous years (1997-2002) became just informative, without any relevance.

Figure 1. Images during floods in 2010

In many days of 2005-2006, the rainfall exceeded the annual average. In 2007, the average was within the features of the dry years. The period from May to August, was considered the driest of the last 40 years. For the first time in Romania, in the summer months, code red has been established, as well as code orange during two months (July-August). Next years, until 2010, they have similar structures as dry years.

In these conditions, massive deposits of sediment appeared in the wider areas of the river cross-sections, where the flow rates are lower. In 2010, there were large quantities of water from snow melting, and the floods occurred. They repeated each time when the rainfalls were more abundant.

Even this year there were floods in the Siret valley (Figure 2). In the analyzed sector, the riverbed Bistrita generally provides a flow easement of 2.8 m^3/s. This flow is maintained until the river Bistrita meets Cracau River and the flow rate increases with an average of 2 m^3/s.

A particular interest is represented by the upstream hydrological regime.

In fact, the hydro channels III, IV, V, and VI, are a constituent part of the basin hydrological Bistrita. The characteristics are directly influenced by the upstream sector due global leakage, floods, the water chemical composition. It has a major impact, through both its specific construction and by its functional characteristics. By analyzing the water supply from the natural intakes and the precipitation, and the consumption and losses, it is possible to estimate the hydrologic stability. The water balance is a possibility to estimate the water reserves.

The monthly average flow has the highest values in the warm season of the year, primarily between the months of March to October, but mainly from April to August. It is achieved when 85% (or 70%) of the annual average flow is reached. From the statistics of the past 20 years (except 2005 and 2007) 18.4% was achieved in July and 16.2% in August. In winter, November to February, the rates drop considerably, reaching a minimum 0.212 m^3/s in January, representing about 2.3% of the annual average.

Figure 2. Images during floods in 2017

The hydrologic balance represents the difference between lake effluent and evaporation. Generally, the evaporated water is compensated by the precipitations fallen directly into the lake. If we consider the ratio of precipitation and evaporation, it results that these lakes belong to an area with excessive humidity. The seepage losses can be located as more important in the downstream left bank of the Bâtca Doamnei accumulation, built in the embankment. It also influences the clogging, by deposition of the suspended material entrained during the floods (Seteanu, I et al. 1998).

Results and Discussion

The numerical model analyzes the unsteady free surface flow rate in rivers with natural riverbeds, considering the sediment transport balance (entered, transported or deposited). The cross sections have arbitrary shapes. For the study case Cracau river was selected (Ackers & White 1993).

It has an average flow rate of 2 m^3/s, but sometimes in spring the flow rate may increase at 45 m^3/s (registered in 2005). Eight cross sections were measured during the 2014 campaign, representing the basis for the simulations. As it may be observed in Figure 3-a, cross-section numbered 2, in the left side of the riverbed there is practically no shore.

Here it is obvious that at high flow rate values, flood may appear and rehabilitation is necessarry. Some cross-sections, for five profiles are presented in Table 2 (Seteanu & Radulescu 2004).

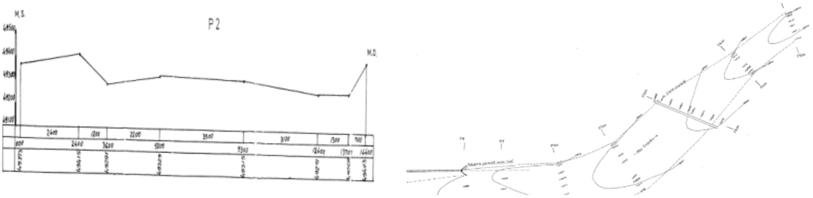

Figure 3. Cross-sections into the riverbed Cracau

In Table 2, x is the horizontal coordinate, measured from the right shore to the left one and y is the altitude, reported to the sea level. An example is presented in Fig.3-a. For Cracau River, there is no database containing long term flowrate values. The maximum values selected for Siret River, Table 3, are correlated with the statistical calculation for hydrograph floods, for Cracau river (Guangqian et al. 2008).

Table 2. The coordinates in cross-sections on Cracau river

Profile 1av		Profile 2av		Profile 3av		Profile 4av		Profile 5av	
x	y	x	y	x	y	x	y	x	y
0	491.06	0	490.33	0	489.88	0	488.31	0	487.43
2	490.14	3	489.53	10	489.78	1	487.02	3	486.25
15	490.25	20	489.93	26	489.23	6	487.32	7	486.45
20	490.86	23	489.27	43	489.27	23	487.52	13	486.95
25	490.73	32	489.38	57	489.08	28	487.09	15	486.45
36	490.46	60	489.3	61	488.24	31	487.82	20	486.51
50	490.14	66	489.58	77	488.37	36	487.87	30	486.81
60	490.87	72	490.1	81	488.04	40	488.31	42	487.65
64	492.1	78	490.07	93	488.09				
		84	490.92	109	488.98				

Table 3. Values of Q_{max} on Siret River

Year	Q(m^3/s)	Year	Q(m^3/s)	Year	Q(m^3/s)	Year	Q(m^3/s)
1970	3186	1983	1420	1996	1612	2009	1984
1971	1966	1984	2460	1997	1040	2010	4470
1972	1842	1985	1400	1998	1380	2011	3872
1973	1535	1986	334	1999	830	2012	2480
1974	1260	1987	275	2000	447	2013	1972
1975	1860	1988	1620	2001	435	2014	2257
1976	630	1989	1370	2002	2200	2015	4680
1977	889	1990	275	2003	796	2016	3342
1978	1320	1991	3270	2004	727		
1979	1280	1992	2045	2005	4650		
1980	989	1993	1020	2006	1375		
1981	2040	1994	604	2007	785		
1982	901	1995	1120	2008	2068		

The mathematical model used in the calculation scheme considers as data necessary for numerical modeling:

- The initial cross-sections profile through the rivers beds (Figure 3-a),
- The distances between the sections and the geographic variation of altitude (Figure 3-b),
- The roughness of the river beds on the analyzed distance,
- The maximum flow rate, the floods hydrograph,
- The time evolution of sediments, concentrations, and dimensions.

In each analyzed section the entered and the transported sediments to the next section were considered. Balances for the deposited sediments are made and appear into the final form of the cross-sections.

To simulate the real, natural flow, it is necessary to know the physics of the phenomena, to establish the significant parameters and the relations between them.

Further, in Fig. 4 some results obtained in the cross-sections are presented.

The areas where sedimentation appeared are mentioned, as well as the erosion sones. Eight cross-sections were considered. For each one the free surface level was determined, in 4 cases of transported flow rate with 10%, 5%, 2% and 1% assurance. In Fig. 4 the results of Sections 2, 4, and 5 at flow rate assurance of 2% and 1% are presented.

In Section 2, the flow channel is deeper than at the beginning. In Section 4 a sedimentation zone appears. Some deposits create an island. The active flow section decreases. In Section 5 two flow channels appear due to the accelerated erosion.

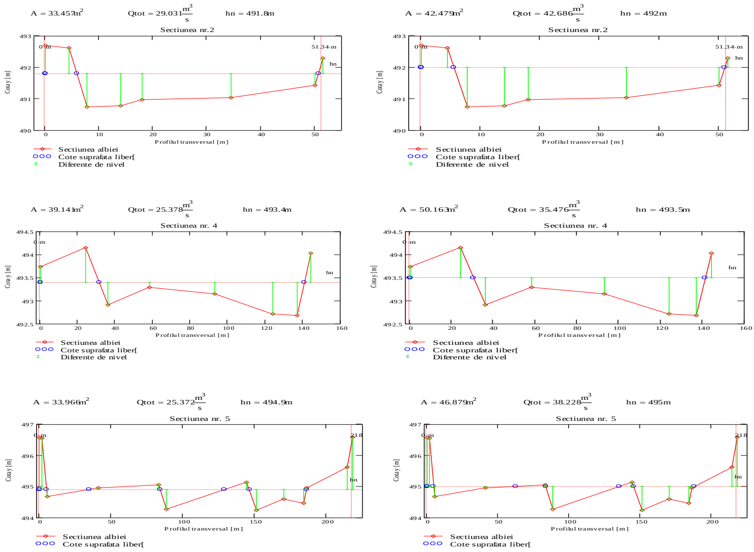

Figure 4. Results into Sections 2, 4 and 5 at two flow rates

For each section the sediments balance was determined. For each flow rate four cases of the roughness were considered. In three case, sedimentation appears on the left shore, especially in sections 5-7. The importance of knowing the exact sediments dimensions must be mentioned. Due to this parameter, during the same flood, in some cross- sections sedimentation appears and in others erosion.

Conclusions

The sediment transport is a current concern related to water management, a complex spatial planning of environmental protection. How this process unfolds, the phenomenon scale, the large significant number of parameters, the direct and indirect practical consequences, having as result often damages, requires the use of computational tools to enable qualitatively forecasting of the sedimentation process. Siret River catchments area was analyzed, well known for the problems concerning the repeated flooding. The numerical model analyzes the free surface non-permanent flow in variable cross- sections of arbitrary shapes. Riverbed-fluid interaction is modeled by three relations referring at the size fractions in the bed before the change of the area of influence, the liquid stream movement transported to the solid phase and the global recovery.

The weights of the initial particle sizes were chosen in accordance with the obtained data from the in-situ measurements. The available data for the solid flow highlights the strong character of the alluvial riverbed of the River Cracau. There is a significant suspensions weight with an excess of small diameter fraction (cvasicoloidal, 0.002 mm). Further sedimentation tendency of the bed, with a surplus of deposits in sections 5-7 appears. A lateral plugging is observed along the valley. It is expected that clogging will continue to evolve, being accompanied by new meanders and islands formation, as a result of solid stock agglomeration in the local concentration points (the induced vegetation increased in some areas).

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References

Nistreanu, V & Nistreanu, V 1999, '*Amenajarea resurselor de apa si impactul asupra mediului',* Editura Bren, Bucharest.

Radulescu, V & Nistreanu, V 2004, *'Sisteme hidraulice de aductiune'*, Bren Publisher, Bucharest, ISBN 973-31-1412-X.

Seteanu, I & Radulescu, V 2004, *'Numerical models in hydraulics and power engineering',* Bren Publisher, Bucharest, ISBN 973-99604-4-8.

Seteanu, I, Radulescu V & al. 1998, *'Sisteme hidraulice, Fundamente si aplicatii'*, Editura Tehnica, Bucuresti ISBN 973-31-1412-X.

Ackers, P & White, W., 1993, '*Sediment transport in open channels: Ackers and White Update. Technical note',* vol. 101, Issue 4, 1993, pp.247-249, https://doi.org/10.1680/iwtme.1993.25490.

Guangqian, W, Xudong, Fu & Gordon, H 2008, 'Analysis of suspended sediment transport in open-channel flows: Kinetic Model based Simulation, Journal of Hydraulic engineering, Vol.134, Issue 3, doi/10.1061/(ASCE)0733-9429(2008).

MacDougall, C.H. 1993, '*Bed-sediment transportation in open channels',* Eos, Transaction American Geophysical Union, doi.10.1029/TR014i001p00491.