QUANTITATIVE ANALYSIS IN THE FLUVIAL GEOMORPHOLOGY

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ABSTRACT

Here we present some quantitative methods applied on three large rivers from Romania: Prut, Siret and Somesul Mic. The exemplified methods are: topographic maps were used to measure the horizontal migration of the channels for the last 140 years; data from the hydrometric gauging stations were used to obtain the vertical variability of the channel over the past 50 years. Both these dating methods were used, in order to extend the study further back in time. The main factor contolling these streams is the human factor and the last 140 years are representative in this sense.

1. INTRODUCTION

Maybe no other domain of geomorphology received so fast and complex the challenge of the approach on quantitative bases as it happened in the fluvial domain. There are well known the works considered today as classic of the geomorphologic team from US Geological Survey led by L. B. Leopold or that from Columbia University, led by A. N. Strahler. Between 1950 – 1960 they launched what today is known in the history of world wide geographical thinking as "the quantitative revolution in geography" (Chorley, 1965). In Romania, the organization of geographical research from the early 70's and the implication of geography in solving numerous practical projects have contributed to the appearance pretty early in the geographical research of the new tendencies displayed at the international level (for example, the emulation of an entire generation given by the general theory of systems from middle 70's is almost equal enthusiastic as the one started in the late 90's by the conceptual applications of hazards and natural risks). And these all happened out of the growing necessity of practical implication of the geography domain, of developing its applicative side because "any science must bring humanity economical, social and cultural gains" (Bunge, 1984).

We have carried on our activity within this general context, the accent, in the present case being placed on the analysis of the fluvial geomorphologic systems. The progress at the international level achieved in the study of these components of the crust relief is an exceptional one, having implicated the most resounding names of geographers as S.A. Schumm, K. Richards, M. Church and others. It is not in our intention to review the results in the approached domain, but rather we want to show which is our own contribution to the fluvial quantitative geomorphology.

In the middle of the 90's we published o work entitled "Quantitative Analysis in Physical Geography" in which we exposed numerous opinions regarding the benefits of

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such an approach, but also the limits or the traps. One phenomenon is certain: the unprecedented development of computer science, of the generations of higher and higher performance computers, of specialized softs for solving multiple problems couldn't keep geography, in its ensemble, away from this phenomenon. Such a technique needs certainty, needs data, needs measurement. This was the tendency in the presentations at the recent European Geosciences Union Assembly (13-18 April 2008, Vienna), within which participated specialists from the world community of physical geography. Quantitative aspects made a special presence in one of the widest variety of applications in the whole world.

As far as we are concerned, in the fluvial geomorphology domain, the most notable results of quantitative analysis we had are related to: (i) the modeling of the shape of the longitudinal profiles and the interpretation in the context of hydrographic network evolution from the Oriental Carpathians; (ii) the anthropic impact evaluation by building dams on the hydrographical systems in Romania; (iii) the analysis of the downstream fining phenomenon and bimodality of river bed material; (iv) the importance of typological appointment of the river beds in order to choose the management and intervention measures; (v) the evaluation of plan stability of the river beds; (vi) the evaluation of the stability in transversal section; (vii) the river beds and the winter phenomena.

Related to these aspects, we will discuss about some applications of research techniques and methods in the field and in the laboratory, the interpretation of the results for the channel processes, as they resulted from our research, as well as from our postgraduates' research.

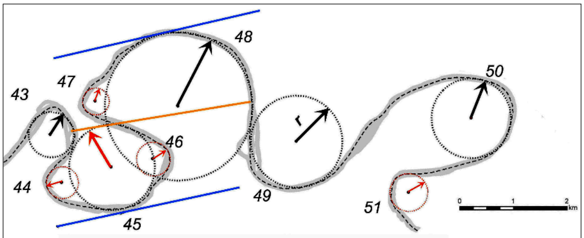
2. THE EVALUATION OF THE MODIFICATION IN PLANE OF THE RIVER BEDS ON THE BASIS OF CARTOGRAPHIC MATERIAL USE

For the typological framing of the river channels and the modification of their type and positions in time, huge success was represented by the analysis of the old maps, the photograms and satellite images. We applied this methodology for the river channels of Prut on the Romanian border, of the Siret river on all its length and of the river Someşu Mic downstream Gilau. The frequency of this method utilization in the research upon the modification in plane of the river channels was to almost 40% by Kondolf and Piegay (2007) on the basis of an inventory of 497 articles of fluvial geomorphology published between 1987 and 1997. It is remarkable that in the recent period the interpretation of the photograms, and satellite images has exceeded as importance the applications on old topographic maps.

In the case of Someşu Mic river, we worked with a set of six series of topographic maps, with scales which varied between 1:28 000 and 1:5 000, covering a period of almost 140 years on a river length of 110 km. For the year 2005 there have been used the orthophotoplans. The topographic maps were processed with the help of GIS software – ArcView 3.2 in order to turn them into a Stereo 70 projection. In the case of the river Siret we worked with two series of topographic maps with the scale of 1:50 000, dating from 1894 and 1973. The identification of the lateral migration of the river was possible by overlapping of some common points, such as bridges, churches, road crossing, altitude level on a river length of over 700 km. In the case of the Prut river we used cartographic materials from 1915, 1980, and for the year 2000 we used satellite images.

For the geomorphologic characterization of the river beds in the established moments of time there is a morphometric data base regarding the features of the entire alluvial lowland of the river, at the active stripe of flood-plain, at the stream channel itself. There have been used two methods of data extraction in the realization of this data base.

The first method consists in the realization of measurements along the river course, regarding the stream channel axis, on the meanders and the meander bends (fig. 1).



Nr.bend	Curvature raw	Meander wavelength	Meander amplitude
43	422.5		
44	801.8		
45	1380.4		
46	855.7		
47	743.4		
48	297.2	2250	2175
49	315.1		
50	249.6		
51	353.0	3700	3200

Fig. 1. Illlustration of meander measurements (Rădoane et al., 2007).

The second method used (fig. 2) presumes the establishment and the maintenance for all the sets of analyzed maps of a defined number of transversal sections, placed perpendicular on the valley axis and in this direction there are made measurements regarding the width of the stream channel, the number of branches, the position of the stream channel axis related to the flood-plain borders, as well as observations regarding the length variations of the stream channel between two consecutive sections.

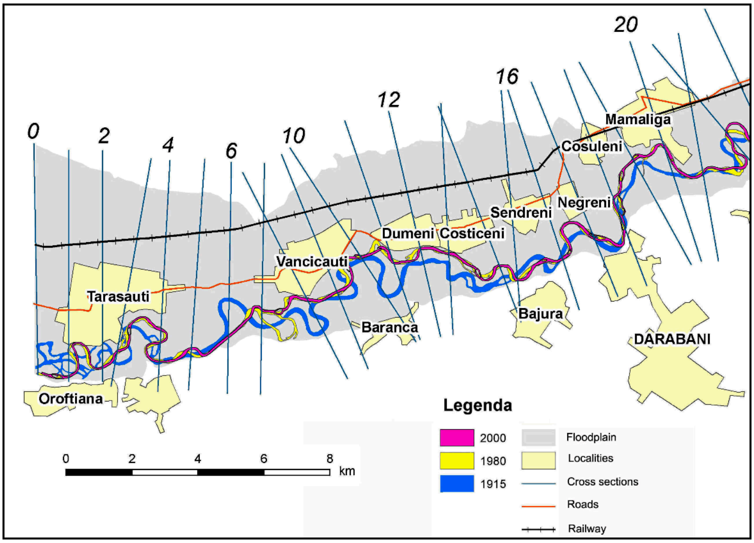


Fig. 2. Model of river channel and floodplain transections for measurements on the morphometrical variables (Rădoane et al., 2007).

Thus, for the Someşu Mic there were established 303 transversal sections, located at intervals of 250 m along the valley axis, for Siret there were established 250 sections at intervals of 2 km, and for Prut, 460 transversal sections, from 1 to 318 located at intervals of 1 km along the valley axis, and from 318 to 460, located at 2 km intervals.

For exemplification in this paper we chose two suggestive variables for rendering evident the use of some quantitative methods in the study of the river bed in time, namely, *the variation of the erosion rate of the shores* and the modification of the *sinuosity index* in different periods of time. Our aim is not detailed and complex analyses upon the presented phenomena, as the space of this work doesn't allow it. But the practical implications, the opening towards other analyses and determinations, the clearing up and the orientations regarding particular causes etc. are undeniable advantages of such an approach.

For the Siret river, by overlapping the two generations of topographical maps, we could determine the lateral migration of the river in 1973 compared to 1894 and for the Prut river upstream the Stânca Costeşti lake, between 1915 and 2000. The obtained value was divided to the period of time between the two topographical surveys and thus we obtained a medium rate of lateral erosion.

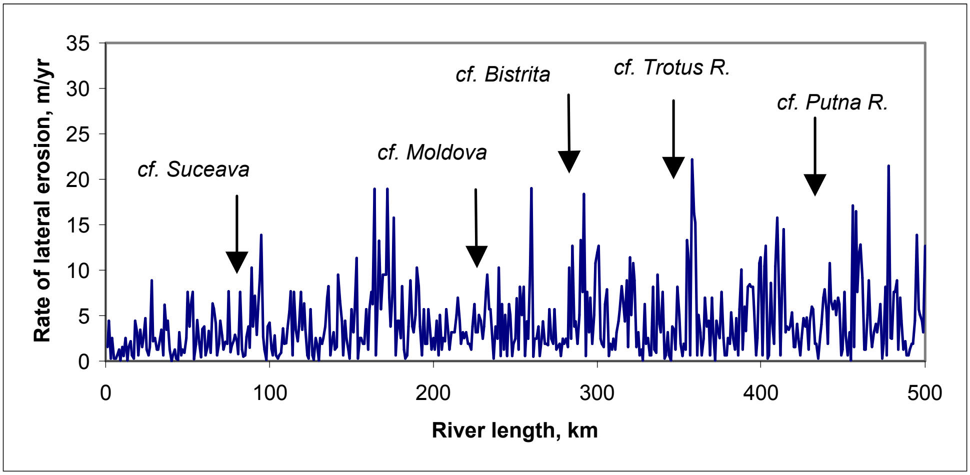


Fig. 3. Lateral erosion along a Siret River channel determined on the basis of topographical maps from 1894 and 1973 (Burdulea, 2007).

The newly obtained variable was represented along the river (fig. 3), and the analysis of this parameter must be related to the river bed typology, to the role of the confluences, to the variability of the discharge and suspended load, to the human interventions and much more. The river oscillated without restraint, mostly in the first period, from a few meters to over 400 meters downstream the confluence with Trotuş, the annual rates varying between 5 and 20 meters. After 1980, the free digression of the river became limited thanks to the interventions for the regularization of the river, embankment and most of all the arrangement of a series of reservoirs.

The advantages of such determinations consist in that they can lead new prognosis equations regarding the risk exposure of the antropogene structures located in the low flood-plain of the rivers. For Siret and for Prut rivers as well, the anthropic use of the floodplain is a big, and in the case of the river Prut, it is a geopolitical problem, the state border being located on the center of the river bed. Or, it is observed that on high erosion levels like 4-5 m /year, time as a anthropogene structure can be affected, and is reduced to a couple of years. Upstream the Stânca Costeşti Reservoir, the lateral erosion rate was determined to maximum values of 11-18 m/year, mostly in the free meander bends.

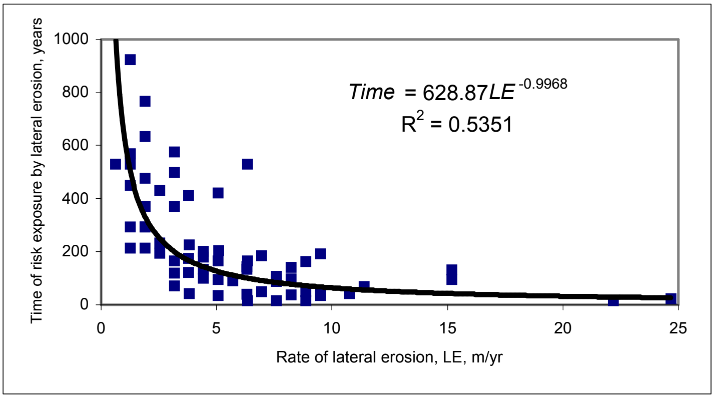


Fig. 4. Time of risk exposure by lateral erosion for the human structures located on the Siret and Prut floodplains.

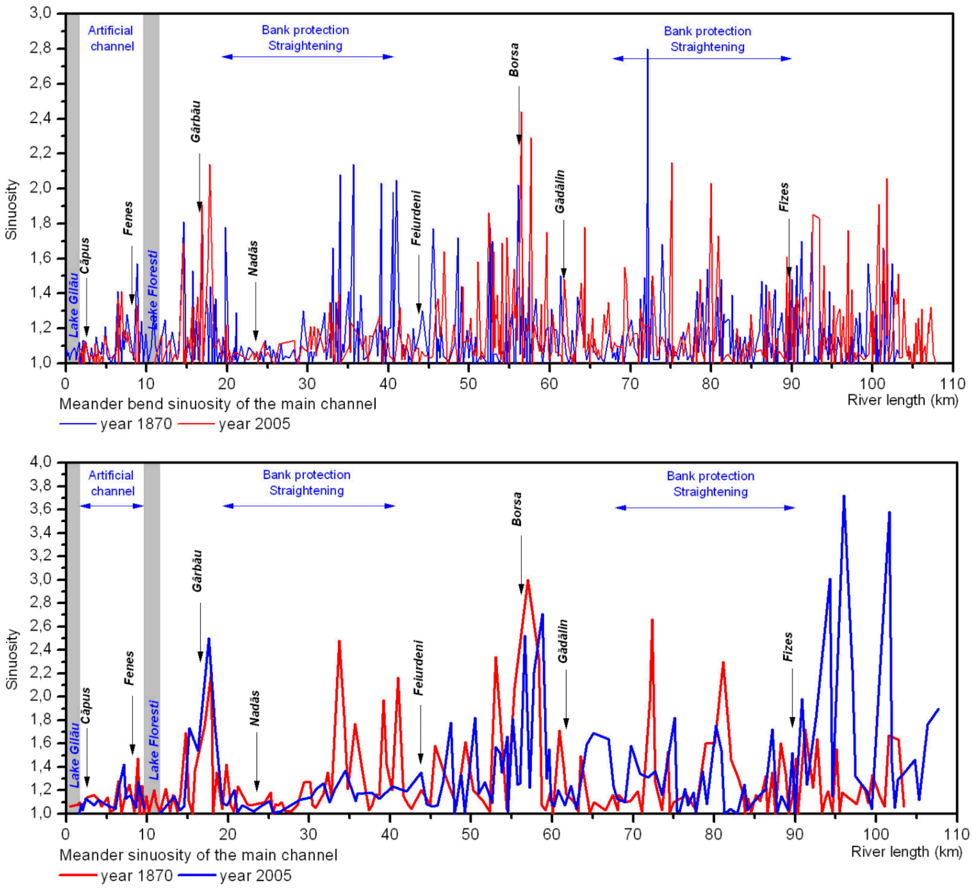


Fig. 5. Adjustability of the Somesu Mic river channel in space and time, by the sinuosity index decreasing between 1870 to 2005 (Perşoiu, 2008).

As about the behaviour of sinuosity, we present the case of Somesu Mic River, the parameter being measured for 6 successive moments: 1870, 1890, 1956, 1968, 1977 and 2005. The meander sinuosity in 1870, when the river is very close to its natural condition, shows us an important characteristic of this river - the high degree of alternation of sinuous, meandering and anastomosed reaches. In an historical perspective, the maximum values of this parameter are obtained for the moment 1890, due to the increase in number and amplitude of meanders. Following this, the values are redistributed, as a consequence of the meander cut-offs, more important during 1890 and 1968 then before, and human interventions starting with 1970. More detailed studies about the planform dynamic of Someşu Mic River and practical implications are in Feier şi Rădoane (2007), Perşoiu (2008).

3. RECENT CHANNEL ADJUSTMENTS IN ALLUVIAL RIVERS USING THE CROSS SECTION CHANGES

The current hydrometric measurements in transversal sections at the hydrometric gage stations represent one of the best modalities to obtain information on aggradation – degradation processes balance in medium and short time (tens of years). These measurements allow us to obtain of time series, respectively, those lines of distance data to a regular time interval. In our research regarding the bed-level change we often applied this methodology, and in the present case we will exemplify some recent determinations for the studied rivers.

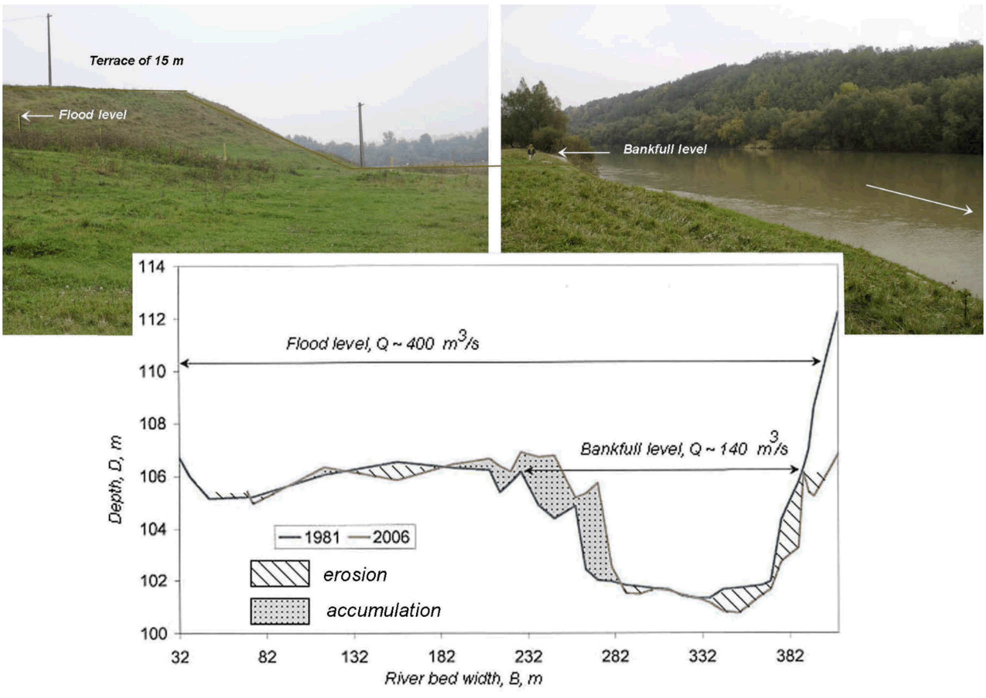


Fig. 6. Cross section changes by the erosion and accumulation processes (Rădoane et al., 2007).

In order to realize the balance the data are graphically respresented for the section form in a rectangular coordinate system, the profile line being the resultant of the value intersection of river bed width, *B*, m and the river bed depth, *H*, m. By overlapping the profiles in successive periods of measurement, there can be visualized the erosions, the accumulation or the respective section stability. The quantification of changes is realized by planimetering the surfaces between two successive profiles and the transformation in cubic m/m (fig. 6). The results are presented in a table as in the Table 1 example.

Tabel 1. Cross sections changes of the Prut River channel by degradation and aggradation. An example for one cross section.

Cross section	Period of measurement	Degradation, D, m^3 /m	Aggradation, A, m^3 /m	D - A, m^3 /m
Rădăuți Prut	81-83	-76.22	8.3	-67.92
	83-85	-7.98	86.04	78.06
				10.14

The balance method was used to all gage stations along the river Prut (Rădăuți Prut, Stânca, Ungheni, Prisecani, Drânceni, Fălciu and Oancea) which covered a period of time between 1975 and 2005. The result (fig. 7) shows which is the fluvial processes tendency for the entire river on the border line of Romania, from which we can deduce the action of the controlling factors, the adjustment effort of the river bed to counteract the massive sediment retention behind the Stânca Costeşti Dam. The aggradation – degradation sequence occurs on a general tendency of river bed deepening, phenomenon due to the Stânca Costeşti Dam effect on the reducing of sediment transport. All the same, the behavior in conditions of no interfering of the river bed is evident through the realization of the feedback loops of the triad erosion-transport-accumulation and which manifest itself through the sequence aggradation-scuyestability-degradation and so on (detailed analyses in Rădoane et al., 2007).

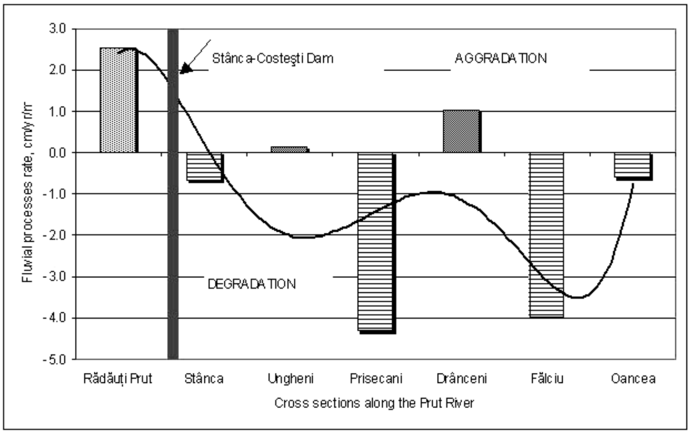


Fig. 7. Succesiunea proceselor agradare-degradare în lungul albiei Prutului în perioada 1978 – 2006 (Rădoane et al., 2007).

The method presented above does not lead to getting a time series respecting the river beds behavior because we don't have control over the regulate time footing. This is why, we have for our disposal another promoted method by us in numerous papers. It is about the obtaining of time series respecting modification of the river beds channel by using tables for the calculation of the discharge at the gage station. An extract from such a table is reproduced in Table 2 which contains a part of the complete measurements in the sections of the gage station on a certain day of the month for the calculation of the discharge, but most of all for the control and adjustment of the rating curve. The last column in the table is the one that can be used for obtaining a time succession with a uniform footing of a month. The medium value on a month is obtained by measurements averaging of 3-6 by month, if the measurement is done on the same profile and if the river is ice bridge free. The graphic expression in fig. 8 clarifies the manner in which the maximum depth of the channel can be use in obtaining the level position of the channel's bed at a certain time.

Tabel 2. A sample from the table of discharge measurements at the gage station

No.	Date	No. of measurement profile	State of the stream	H on the gage ruler, cm	Q discharge m³/s	H max, cm	H-Hmax, cm
1	9-I. 1982	1	open flow	132	0.410	20	112
2	14-I	1	"	131	0.510	20	111
3	21-I	2	ice to the bank	168	0.480	56	112
4	11-II	1	"	149	0.601	33	116
5	17-II	1	open flow	133	0.513	21	112
6	2-III	1	"	138	1.240	28	110
7	11-III	1	"	147	1.830	31	116
8	27-III	1	"	136	0.695	21	115
9	31-III	1	"	148	1.560	34	114
10	2-IV	1	"	150	2.390	38	112

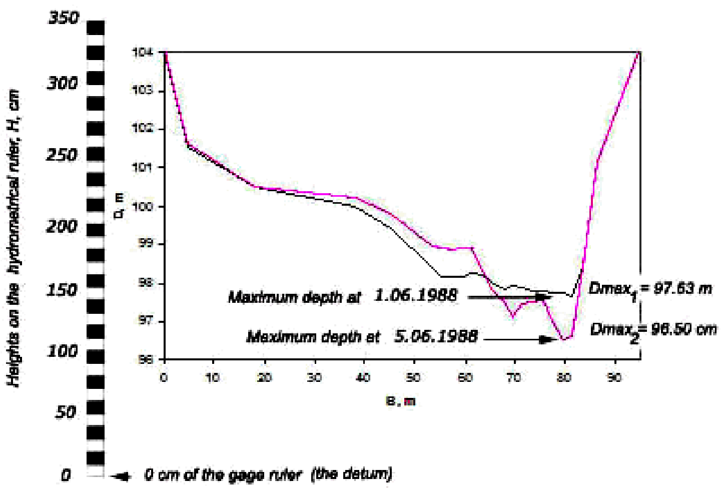


Fig. 9. Illustration of the bed elevation estimation using the thalweg position to the gage ruler datum.

Such a method was applied to over 80 river sections equipped for hydrometric measurements from the Eastern Carpathians (Rădoane et al., 1991). The maximum period for which it was possible the obtaining of a time succession was 40 years. In this paper work we exemplify the time successions of the channel bed oscillations of the Siret river in three sections, upstream and downstream the reservoirs for a period between 1968 and 1998, the time footing being a month (fig. 10).

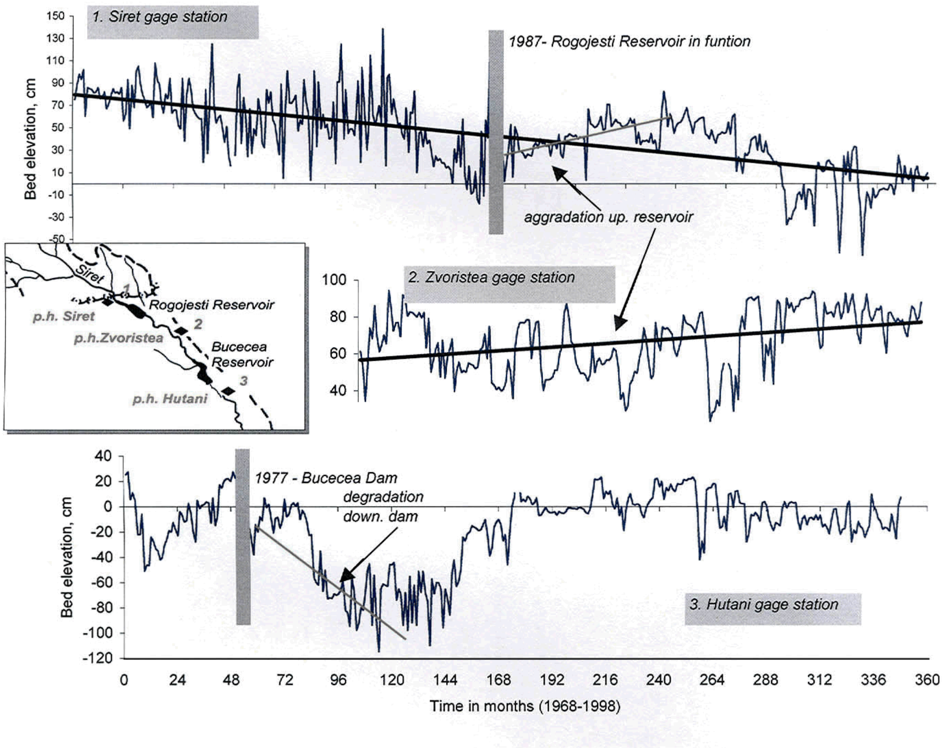


Fig. 10. Time series of the Siret bed elevation în three gage stations along the river. To note the ffect of the dams and reservoirs on the bed elevation change (Burdulea, 2007).

On the abcise we mentioned the apparition of the two dams, Rogojeşti, downstream the Siret hydrometric station, and Bucecea, upstream the Huțani hydrometric station. There are two types of the channel bed oscillations: some with a small period, like months, characteristic to floods, when the channel responds by deepening, first off all, and accumulation to the end of the flash flood; some others, with a longer period, years and tens of years when the channel responds threw degradation or aggradation to the abrupt change of the control factors. In the present case, the bigger impact on the stream channel bed had the arrangement of dams and lakes which had abruptly modified the liquid discharge regime, but mostly of the solid discharge. The answer is the aggradation tendency upstream the lakes (to the Siret and Zvoriştea hydrometric stations, obviously) and the degradation downstream the dams (to the Huțani hydrometric station). As it can be observed on the oscillations graphics of the channel bed, the channel response through aggradation and degradation to the arrangement of the two reservoirs lasted only 6-7 years, after that the channel reached that point of adjustment which determined it to modify one more time the channel processes orientation: degradation to the Siret hydrometric station and aggradation to Huțani (fig. 10). A serie of pictures taken from our field researches are sugestive to illustrate the river bed behaviour in the aggradation case, in the degradation case or in the balanced fluvial processes case (fig. 11).

Fig. 11. Illustration on the river bed behaviour at the certain fluvial processes: aggradation, Trotus River at Adjud (piers are buried in 3 m of sediments)(A); degradation, Suceava River at Suceava (transversal pipes were initially buried at 2 m in the sediment, and today, after 20 years, these are digged out)(B); degradation, Somesu Mic River downstream Cluj Napoca, where the bedrock is uncovered (C); erosion and accumulation in balance, Somesu Mic at Someseni (D) (foto N. Rădoane, A. Perşoiu).

We stop just with these summary commentaries, our aim is to show the opportunity of using quantitative methods in the river channels study. The presented methods have been used in our numerous papers, but also by other authors and they led to the obtaining of precious information about the river channels behavior in normal conditions of evolution or to stress factors. But even more important was the fact that such an approach permits the realization of valuable forecasts on the morphological changes in the river domain, so necessary in the management of this relief components (Rădoane, Rădoane, 2007). The interpretation of the obtained results through the quantitative approach does not leave any room for many speculations if there exists a well knowing of the geomorphology history of the studied river, not only about the channel itself, but also related to the transformations and interventions within the drainage basin, to the outflow dynamic, to the climatic variability, to the land use.

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