Available online at www.sciencedirect.com

SCIENCE DIRECT®

Geomorphology 71 (2005) 112–125

GEOMORPHOLOGY

www.elsevier.com/locate/geomorph

Dams, sediment sources and reservoir silting in Romania

Maria Rãdoane*, Nicolae Rãdoane

Department of Geography, University "Stefan cel Mare", Suceava, 5800, Romania

Received 15 December 2002; received in revised form 8 April 2004; accepted 9 April 2004
Available online 22 April 2005

Abstract

Romania ranks among countries with the greatest achievements in the field of dams in the world. Among the 80 membership countries of the ICOLD, Romania ranks 19th in "large dams" and the 9th in Europe. The reservoirs arranged behind dams are characterised by small capacities, generally under 200 million mc. The total number of big dams is 246, among which almost half are dams under 40 m in height. The highest dam is Gura Apelor, on Râul Mare, in the Retezat Mountains and it is 168 m. We can add to these other 1500 dams, under 15 m in height, with the reservoirs having capacities under 1 million m^3. The anthropic intervention through the arranging of dams and reservoirs in the river systems of Romania's territory is significant and justifies the concern of geomorphologists to know the relations between the dynamics of the landscape and the behaviour of these anthropic structures.

This work refers only to one of the processes that reservoirs undergo once they are placed in a river system—the silting. More precisely, we try to make a synthesis of the knowledge stage of the reservoirs silting in Romania that we want to approach on the basis of the relations with our territory morphodynamics and considering the substantial accumulations of new data. The total erosion rate from Romania's territory is, on the average, 125 million tons/year out of which 45–50 million tons/year are transferred by rivers.

We analyzed 138 reservoirs with initial volumes between 1×10^6 m^3 and 1230×10^6 m^3 for which there is a determination of the silting time. The situation of the reservoirs silting from Romania is as follows: very serious for 15 dam reservoirs with average dimensions of 8 million m^3, all of them situated in the Sub-Carpathian area, one of the important sediment production areas (over 500 tons/km^2/year), with the silting time T50 of these reservoirs having values between 2 and 10 years; serious for 30 reservoirs, with average capacities of 35 million mc, and the silting time T50 between 10 and 50 years. In this case, the reservoirs are also situated in the area of important specific sediment production of over 250 tons/km^2/year (the case of the rivers Olt, Argeş, Buzău, and Bistriţa but also of the reservoirs in the Bârlad basin), many of them being arranged as a cascade of small reservoirs on the main rivers; difficult for 13 reservoirs, with a silting time < 100 year and which are usually situated in the area at about 200 tons/km^2/year.

Keywords: Construction of dams; Sediment sources; Reservoir sedimentation; Morphodynamic features of Romania's territory

---

* Corresponding author. Fax: +40 230 520080.
E-mail address: radoane@usv.ro (M. Rãdoane).
URL: http://www.usv.ro/istgeo (M. Rãdoane).

0169-555X/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.geomorph.2004.04.010

1. Introduction

Dams and the reservoirs created behind them have represented a domain of interest for geomorphology, especially for its dynamic branch, because it has been stated that such anthropic structures cause irreversible changes in the dynamics of the fluvial systems. The issue has been debated in a series of works and PhD theses, especially by the research team from "Stejarul" Research Station from Piatra Neamţ, but also by researchers from other domains of activity. The arguments brought forward deal especially with the fact that nowadays the large dams of the world with their hydrographic systems have been (in most part and some of them totally) controlled by dams with their reservoirs, with a water volume of 5–6 times the average discharge of all the rivers in the world, estimated at almost 1250 km^3/s (Ichim and Rădoane, 1986). The arrangement of transversal dam work introduced great discontinuities in the transportation of sediments, in the evolution of riverbeds, and in the adjoining slopes, which in geological time are controlled with a very reduced rate of manifestation by the tectonic movements and the variations of the general base level. As for the development in space and the duration of manifestation of the influence of such anthropic structures, Williams and Wolman (1984) estimated, on the basis of the analysis of an important number of cases, that the course of big rivers may be hundreds of kilometers and the duration thousands of years. Or, as we shall see, such structures are to be found also in Romania having a total volume of almost 13 billion m^3 (one third of the entire volume of water carried in 1 year by the interior rivers). Moreover, they are accompanied by the dislocation of important amounts of rocks, by terrigenous materials, which, only between 1950 and 1990 in the context of hydropower arrangement, have totaled 500 million m^3 of embankment, 771 km of dams, 33 million m^3 of surface concrete and, 12 million m^3 of underground excavations on 669 km of drifts.

This work refers only to one of the processes that reservoirs undergo once they are placed in a river system—the silting. More precisely, we try to make a synthesis of the knowledge stage of the dam lakes silting in Romania that we want to approach on the basis of the relations with our territory morphodynamics and considering the substantial accumulations of new data. The factual material that we have is structured as follows: (i) the construction of dams and the arrangement of reservoirs in Romania, (ii) the problem of sediment sources and, (iii) the silting of reservoirs.

2. The construction of dams and the arrangement of reservoirs in Romania

Romania is known as a country where the tradition of dam construction and the arrangement of lakes is very old (Fig. 1). The Saard and Cristurul Pools near Turda are from the twelfth century. The oldest reservoir dates from as early as 1780, whose dam of 23 m and after several repairs is still functional—Tăutu Mare Reservoir from Metaliferi Mountains was built for the gold mines. Since the fifteenth century in Romania much interest has been shown for the arrangement of rivers with small accretion and waterfalls. Documents are available that certify pools as early as 1448; and the Braşov area, according to some historical documents, between 1503 and 1550 there were 28 pools. In another old document, Moldova was described as rich in pools, some of them probably existing at least from the period of Stefan cel Mare (the reservoirs Hârlău, Belceşti, Sipote, Dinischean); and others were arranged later, especially during Alexandru Lăpuşneanu's and Vasile Lupu's reigns. Moreover, in Vasile Lupu's period, Dracşani Pool was enlarged; and it is still considered to be one of the largest pools in Romania (surface area = 486 ha and capacity = 5.5 million m^3).

The modern and contemporary period marked in Romania an increasing interest in the arrangement of waterfalls for hydropower purposes. So that at the end of the nineteenth century the first hydroelectric power stations were built on Dâmboviţa in Bucharest (1890) and on Sadu near Sibiu (1896) without having too much water accumulation. The ample study about the hydropower reserves by the brilliant scientist Pavel (1933) may be considered the first synthesis on arrangement conditions of dams and on dam reservoirs in Romania. Until 1940, only 128 hydropower plants had been built, but the water accumulations were not so important. Starting from the 1960, the pace of arranging reservoirs became faster, culminat-

Fig. 1. Locations of dams built in Romania in ancient times and the Middle Ages (Dascalescu, 2000).

ing between 1980 and 1990 when 78 reservoirs were put into operation (Figs. 2 and 3).

After this period, a severe decline of dam constructions was registered between 1991 and 2000, when only 17 dams from those which had already been started were finished. This dynamic is also graphically illustrated in Fig. 4, which indicates the pace of dam construction in Romania in the twentieth century, after the official data published by the Romanian Committee for the Big Dams (2000). At present, the data indicate that Romania is among the countries with the greatest achievements in the world

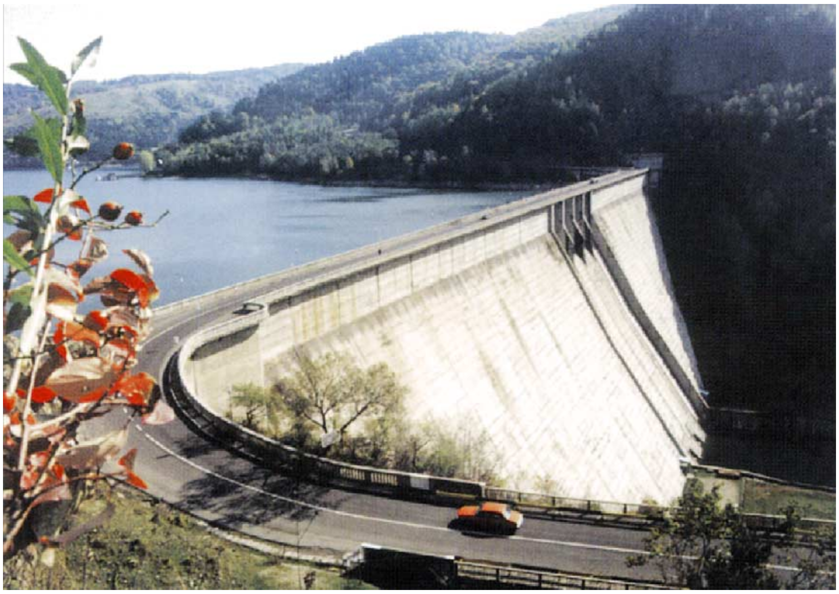

Fig. 2. Izvoru Muntelui Dam, no. 27 in Fig. 8 (height = 127 m; length = 430 m; reservoir volume = 1230 million m^3).

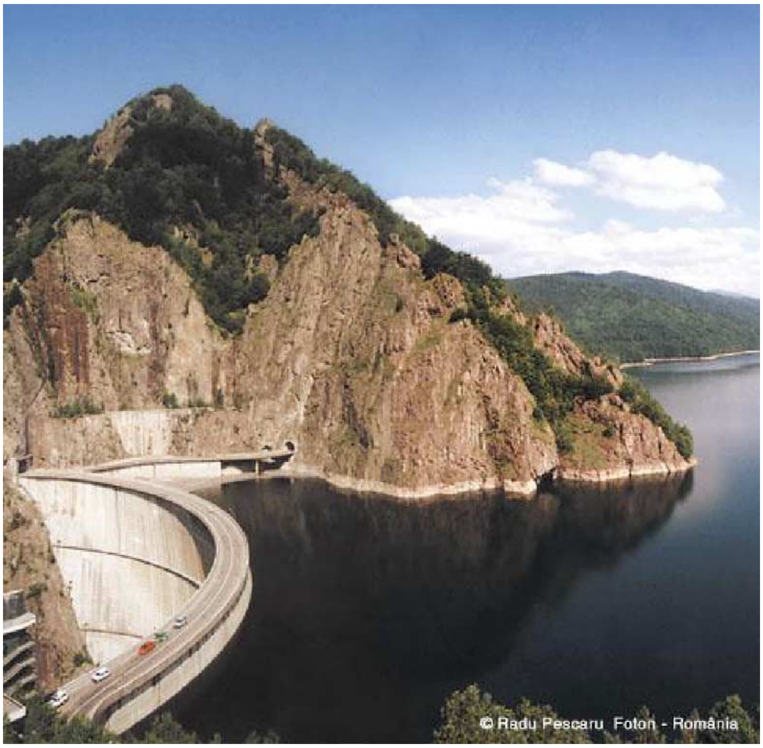

Fig. 3. Vidraru Dam, no. 1 in Fig. 8 (height = 166 m; length = 480 m; reservoir volume = 465 million m^3).

regarding dams, which also allowed technology export (Algiers, Iran, Turkey). Among the 80 country members of the International Committee of the Big Dams, Romania occupies the 19th place regarding the number of “big dams” (considered over 15 m height) and the 9th place in Europe. The total number of big dams is 246, among which almost half are dams under 40 m height. The highest dam is Gura Apelor on Râul Mare, in the Retezat Mountains, and it is 168 m. We can add to these another 1500 dams under 15 m height, with reservoirs having capacities under 1 million m^3.

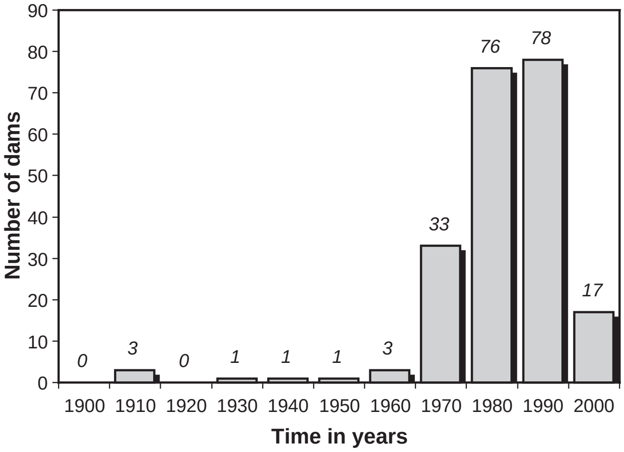

Fig. 4. The rate of dam construction in Romania in the twentieth century (data offered by the Romanian Committee of the Big Dams, 2000).

As a conclusion, we can estimate that the anthropic intervention through the arranging of dams and reservoirs in the river systems of Romania's territory is significant and justifies the concern of geomorphologists to know the relationship between the dynamics of the landscape and the behaviour of these anthropic structures.

3. The sediment sources

The position in a temperate-continental climate and the presence of the Carpathians is defining for the distribution and the system of the geomorphologic process, generating sediments, and expressing, finally, the morphodynamic specific of a territory. This is also the reason why a great importance was given to the problem of sediments flowing on Romania's rivers, as an indirect expression of the dynamic state of the landscape. Beginning with the main work of Diaconu (1971), we had, for the first time, a global image of the susceptibility to erosion of our country's territory and of an overwhelming importance for time predictions about dam reservoir silting. Two theses concerning a general perspective over the dynamic of the Romanian relief have been subsequently elaborated. The first, written by Moţoc (1984), proposes a general image over the whole territory of Romania, referring to sediment delivery in comparison with the major types of morphogenetic processes and the main unities of our country's landscape. It is a pioneer work as far as Romania is concerned. The other synthesis was published by Mociorniţa and Brateş (1987), who updated the outflow map after 1970–1980 when most of our rivers reached the maximum discharges with a recurrence interval of 100 years. It is a work that relies on the entire database resulting from the national measurement network over a more than 35 years period. Other updated syntheses have not been known after this date, except for re-editions and interpretations of the above mentioned works.

As far as we are concerned, on the general context concerning the sediment source problems, a new synthesis has been given (unfortunately it has not been realised for the entire territory of Romania, but a large part has been treated) on the basis of an updated database. Our approach focuses on the definition of the sediment sources such as: (i) source area related to the slope basin or riverbeds and with land use (agricultural, forest, buildings, mining, etc.) and (ii) in comparison to the generating processes, namely, those that make transition to and into the riverbeds of sediments.

The processing of a large amount of data obtained from various sources (measurements in hydrometric cross-sections from the national network ensured by the Romanian Waters Administration, indirect estimations because of sediment stock from some reservoirs, personal measurements on small basins) has led us to the selection of two control factors as criteria of sediment source analysis for a large territory such as Romania. They are: (i) the lithological composition of the rock generator sublayer and (ii) the size of the drainage basins that provide a selection of the amount of the sediments conveyed from the origin area to the discharging area. The choice of these two factors is also motivated by arguments acquired from the specialty literature analysis (that is authors who have suggested prognosis models of the sediment yield, such as: Gregory and Walling, 1976; Dietrich and Dunne, 1978; Jansson, 1982; Griffiths, 1981; De Villiers, 1985, etc.), but also from personal experiences (the model of multiple regression for the estimation of the sediment yield in drainage basins with 400 km^2; Ichim et al., 1987).

Our proposal focused on acquiring some predictive equations of sediment yield for Romania in which the two controlling factors (the lithologic substratum and the size of the drainage basins) should be considered independent variables. The database that we had at our disposal refers to 212 cross-sections controlled by basins varying from 0.17 km^2 to over 10 000 km^2 from 13 areas in our country and were lithologically and geomorphologically different. The data processing consisted of many stages that have ultimately led to the equations listed in Table 1. These relations are rendered in Fig. 5, from which we can easily infer that for Romania's territory there is a considerable variability of sediments generating in different areas of the country. These equations are power functions, and their parameters (mainly a and b regression coefficients) can be used in subsequent classification analysis.

Regression coefficient a has values from 42.861 to 10 006.4. Its meaning in the relation is that it is closely

Table 1
The centralization of the relations between the specific sediments production and the drainage basin area for various morphological conditions in Romania (SY=sediment yield; A=drainage basin area)

Description of the area	Statistic parameters of $SY=aA^b$ relations				No. of observations (n)
	A	b	r	R^2	
(1) The flysch mountain area (the Eastern Carpathians)	738.48	−0.167	0.799	0.639	49
(2) The Neogene molasse area (the Eastern Sub-Carpathians)	5677.47	0.220	0.904	0.817	35
(3) The Neogene molasse and Quaternary deposits area (Sub-Carpathians and Getic Piedmont)	9367.43	−0.277	0.647	0.419	11
(4) The crystalline mountains area (Jiu)-mining influences	320.40	−0.103	0.364	0.133	12
(5) The Neogene molasse area (Jiu-Olteţ)	2094.93	−0.175	0.879	0.772	18
(6) The Getic Piemont (on the basis of lake sediments)[a]	10006.40	−0.194	0.336	0.113	6
(7) The crystalline mountains area (on the basis of lake sediments)[a]	1450.82	−0.124	0.746	0.557	4
(8) Small basins in the crystalline mountains area[a]	42.86	−0.007	0.451	0.203	8
(9) Moldavian Plateau (Bârlad)	2203.00	−0.318	0.670	0.449	15
(10) Moldavian Plateau, Moldova Plain (Jijia)	3217.98	−0.432	0.362	0.131	13
(11) Oltenia Plain	268.27	−0.284	0.511	0.261	12
(12) The crystalline and volcanic mountain area (Someş-Vişeu)	361.16	−0.224	0.491	0.241	12
(13) The region of the internal flysch (Someş-Vişeu)	435.25	−0.073	0.212	0.045	17

[a] The bed load was taken into calculation.

connected to the actual conditions for which the function was created (mainly morpholithological in our case). From this point of view, *a* regression coefficient can be used in cluster classification analysis.

Regression coefficient *b* denotes the inclination degree of the slope regression line. In our case, it varies between −0.0072 when the regression line is almost horizontal and −0.4316 when the line is more

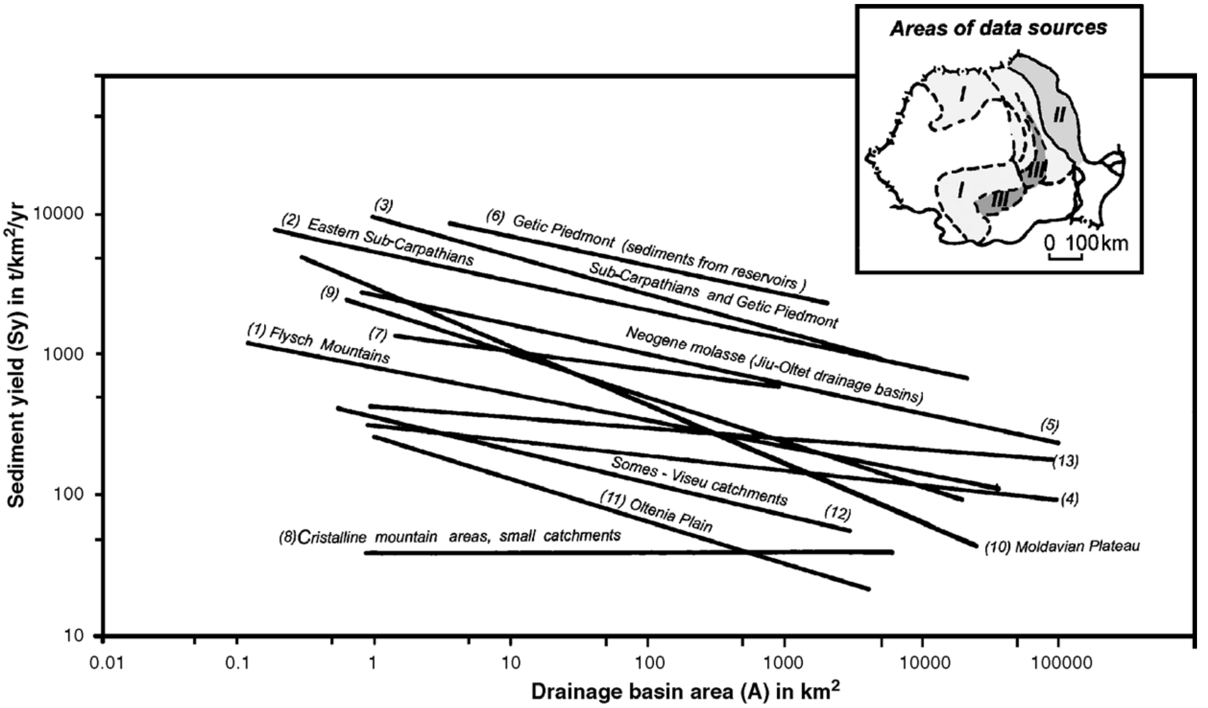

Fig. 5. Relationships between the sediment yields and the drainage basin areas for different morpholithological conditions of the Romania (numbers correspond with Table 1).

inclined; therefore, sensitivity is a higher. The other statistical tests have helped us to accept or refuse the predicative significance of the equations, some of them being less sensitive then the others.

Cluster analysis was applied in order to find the best groups among the great number of studied data, on the basis of which we should realise a territory regionalization with a similar power of generating sediments. With that end in view, we used the regression coefficient a, whose variation synthesizes the complexity of the morphological and morphodynamic conditions in a certain area. The clusters were fixed by calculating the variance-within-the-groups and the variance-among-groups, according to the methodology described by Johnston (1986). The graphic result is rendered in Fig. 6 where it is observed that the coefficients tend to group into three clusters.

Cluster I brings together most of the coefficients (in which four groups have been concentrated) and characterizes the zones with sediment yield of under 700 tons/km^2/year. These zones include most of the regions in our country: Moldova Plain, Oltenia Plain, the area of the internal and external flysch, the crystalline zone, and the volcanic mountains.

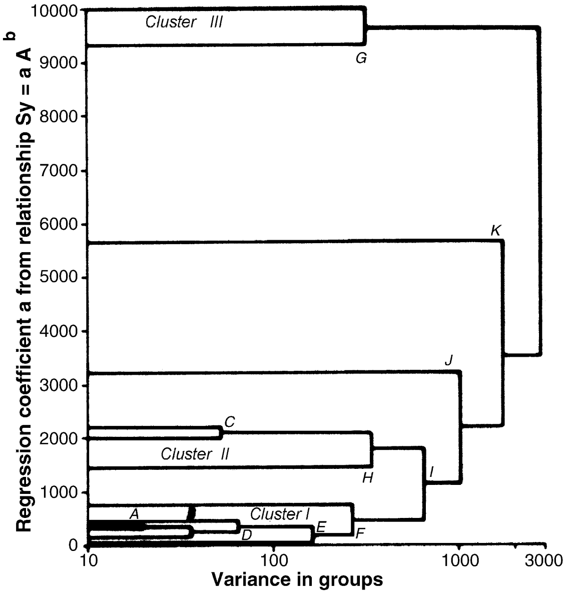

Fig. 6. Cluster analysis on the a regression coefficients from the relationship Sy = f (A) for the morpholithological conditions of Romania.

Cluster II is made up of two subgroups and characterizes the zones with sediment production of about 2000 tons/km^2/year, mainly the Moldavian Plateau and the Getic Plateau.

Cluster III characterizes the exceptional sediment productions registered by some small basins in the Bend Subcarpathians and the Getic Piedmont.

On the basis of this classification, we have obtained generalized relations $Sy=f(A)$ (Fig. 7) for the mentioned groups, which may be compared to Walling's generalized tendencies (1983) for different regions of the world. The general observations to be kept in mind from this analysis are that

(i) In Romania's case, the sediment transit is "delayed" from the source area to the delivery area, expressed by the negative relation of the specific sediment production once the size of the drainage basin has increased. The phenomenon is due to the selective transportation of the sediments inside a drainage system. This "loss of sediments" takes place on the slope of -0.190 for the areas in Clusters I and II and on a higher slope of $b=0.328$ for the areas in Cluster III.

(ii) Most of Romania's territory enters the global centralized tendency belonging to Walling (1983), with a regression slope of -0.125. We may estimate that the areas in Cluster I, which characterizes most our country's morpholithological areas are placed in the regression line of maximum intensity areas, a situation that may be assimilated to a medium condition of specific sediment production for the most part of the globe. On the contrary, the second and third group, although characterizing areas with little extinction (the bend sub-Carpathians and Getic sub-Carpathians), are registered as some of the most productive alluvial suppliers in the world.

4. Reservoir silting

Interest in the reservoir silting study decreased immediately after the dam construction slowed down

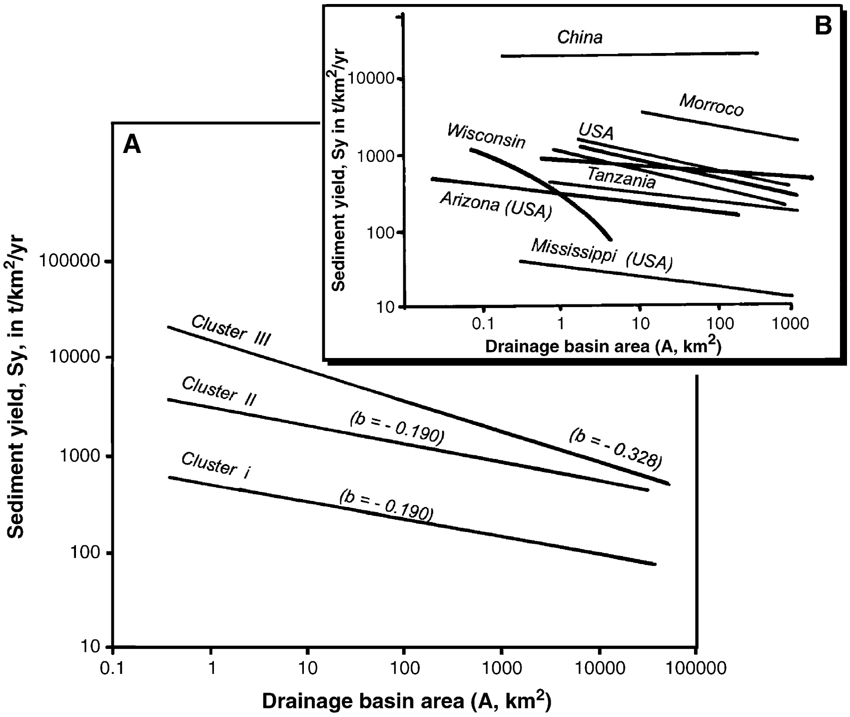

Fig. 7. Generalized relationships between the sediment yield and drainage basin area for the Romania's territory (A) and obtained by Walling (1983) for different conditions of the world (B).

in Romania, although the present reservoirs need attentive supervision from this point of view. But we must not neglect the fact that a study on the silting of dam reservoirs needs an expensive price, the main reason for which the research in this domain has decreased lately. As far as we are concerned, we have a rich experience in the study of the phenomenon and an important database that helps us approach the problems of better knowing the dam reservoirs silting in Romania (the way it is now), and in trying to relate it to the morphodynamic characteristics of our country's territory to highlight the extreme situations and the possible causes of this process.

The database on which our observations are based, includes, on the one hand, a situation on the dimensions of the lacustrine basins (capacity, area, position inside the hydrographic basin); on the other hand, a situation on the silted volume of the basin and an evaluation of the silting time of 50% of the initial storage capacity of the lake. All these data have been obtained from extremely different sources, from our own research on some lakes in Bistriţa Valley, Siret Valley, and Buzău Valley to attentive research of scientific production appearing in the last decades: the archives of The Institute of Hydropower Studies and Projections, The Romanian Committee for Great Dams, National Institute of Meteorology and Hydrology, Aquaproject, and others. Because of the small area that our work covers, we will present a part of this statistical data in the form of a table (Table 2).

The estimation of the stage of the reservoir silting requires some knowledge about the initial capacity of the reservoirs: of a parameter that is called accumulations coefficient (α) and that is defined as the relation between the volume of the drainage basin's flow drain and the reservoir's initial capacity; and of another parameter that is called silting time, of 50% from the reservoir's volume (T50). The analysis of these parameters has been done on the basis of a correlation with the morphodynamic features of

Table 2
The silting situations of some reservoirs from Romania (their position is showed in Fig. 6)

No. of reservoir	Drainage basin	Reservoir	Drainage basin area, A, km^2	Initial volume 10^6 m^3	Silted volume %	Year of construction	Period of investigation (years)	Source
1	Argeş	Vidraru	286	465.00	0.43	1967	11	Ionescu (1980)
2		Oieşti	441	1.80	74.00	1967	23	Ichim et al. (1994)
3		Cerbureni	480	1.62	68.00	1966	11	“
4		Curtea de Argeş	570	0.89	88.00	1972	13	“
5		Zigoneni	625	13.30	23.70	1973	13	“
6		Vîlcele	696	41.50	8.42	1977	11	“
7		Budeasa	1100	30.80	8.30	1980	8	“
8		Bascov	1162	5.40	93.00	1971	7	“
9		Piteşti	3085	4.80	85.00	1970	6	“
10		Golesti	3100	107.90	1.95	1983	6	“
11	Doftana	Paltinu	334	56.00	4.00	1972	17	Roşca (1987)
12	Ialomiţa	Pucioasa	448	10.60	33.50	1974	13	Ionescu (1980)
13		Săcele	170	18.30	6.02	1976	12	“
14		R. Vălcea	15285	21.40	73.20	1974	13	“
15		Dăeşti	15143	11.70	39.10	1976	8	“
16	Olt	Rîureni	15536	7.30	14.00	1977	8	“
17		Govora	15727	18.50	27.00	1975	3	“
18		Băbeni	16847	59.65	8.30	1977	5	“
19		Străjeşti	18229	202.70	3.20	1978	5	Roşca (1987)
20		Ioneşti	17222	24.90	2.50	1980	6	“
21		Zavideni	17480	51.20	2.18	1979	6	Ionescu (1980)
22		Dragasani	17691	66.60	1.28	1980	6	“
23	Mureş	Cinciş	301	43.00	3.50	1969	21	“
24		Bucecea	1983	14.40	32.30	1978	18	Olariu (1992)
25		Galbeni	19445	40.00	59.60	1983	12	“
26		Poiana Uzului	420	170.00	5.11	1975	20	“
27		Iz. Muntelui	4025	1230.00	1.30	1962	27	Rădoane (2002)
28		Pîngăraţi	5144	6.70	48.00	1964	23	Ciaglic et al. (1973)
29		Vaduri	5220	5.60	11.40	1966	16	Rădoane (2002)
30		Bîtca Doamnei	5229	10.00	27.20	1966	24	“
31		Piatra N.	5232	12.00	3.40	1966	8	“
32		Racova	6566	8.60	50.40	1964	21	Olariu (1992)
33		Gîrleni	6633	5.10	25.30	1965	17	“
34	Siret	Lilieci	6727	7.40	10.70	1966	17	“
35		Bacău	6763	7.40	18.40	1966	20	“
36		Belci	1093	12.00	50.00	1964	27	“
37		Puşcaşi	336	17.20	62.30	1973	25	Purnavel (1999)
38		Antoheşti	40	0.22	40.91	1984	11	“
39		Găiceana	47	0.41	41.46	1984	11	“
40		Cuibul Vulturilor	542	9.50	32.63	1978	14	“
41		Rîpa Albastră	253	10.60	21.13	1979	14	“
42		Solesti	414	52.70	1.14	1974	11	“
43		Fitichеşti	163	5.50	52.60	1977	16	“
44	Prut	Pod Iloaiei	525	37.00	32.30	1964	11	Zavati and Giurma (1982)
45		Cucuteni	122	14.00	5.43	1964	10	“
46		Ezăreni	41	3.50	13.60	1963	12	“
47		Ciubeşti	81	12.30	5.20	1963	12	“
48		Aroneanu	47	8.30	19.98	1964	11	Pricop et al. (1988)
49		Stanca	12000	1400.00	2.50	1978	8	Rădoane (2002)
50	Iad	Lesu	89	28.30	0.06	1973	1	“
51	Gladna	Surduc	135	50.00	2.40	1976	9	“

Romania's territory. Moreover, the table was completed with a map that indicates the repartition of the reservoirs following the latest data supplied by the Romanian Committee for the Big Dams, superimposed over the map of the specific production of sediments on Romania's territory (map brought up to date as well; Fig 8).

4.1. Concerning the capacity of the lacustrine basins

As one can see from the graphic representations belonging to Fig. 9A, the reservoirs in Romania are characterised by relatively small storage capacities. Almost 90% of the existent reservoirs have capacities under 200 million m^3 and among these, half of them have capacities under 20 million m^3. The relief conditions and the conditions concerning Romania's river flow offered fewer changes for the arrangement of big dams and, implicitly, of big lakes. The only exceptions are few: the Izvoru Muntelui Reservoir (the biggest among the interior rivers of our country), Vidraru on Argeş, Vidra on Lotru, Siriu on Buzău, Gura Apelor on Râu Mare, etc. A lot of the existing rivers are arranged with waterfalls (Bistriţa, Siret, Buzău, Argeş, and Olt) with specific exploitation conditions, which reflects directly over a certain silting rate. This is how the large number of lakes on the rivers Olt, Argeş and Siret (illustrated on a graphic in Fig. 9B) are to be explained. The reservoir capacity and the exploitation conditions are important elements, which control the sediment restraining degree and sediments from the source area.

The capacity of lakes is decisive for the evaluation of the rhythm and of the silting time due to very

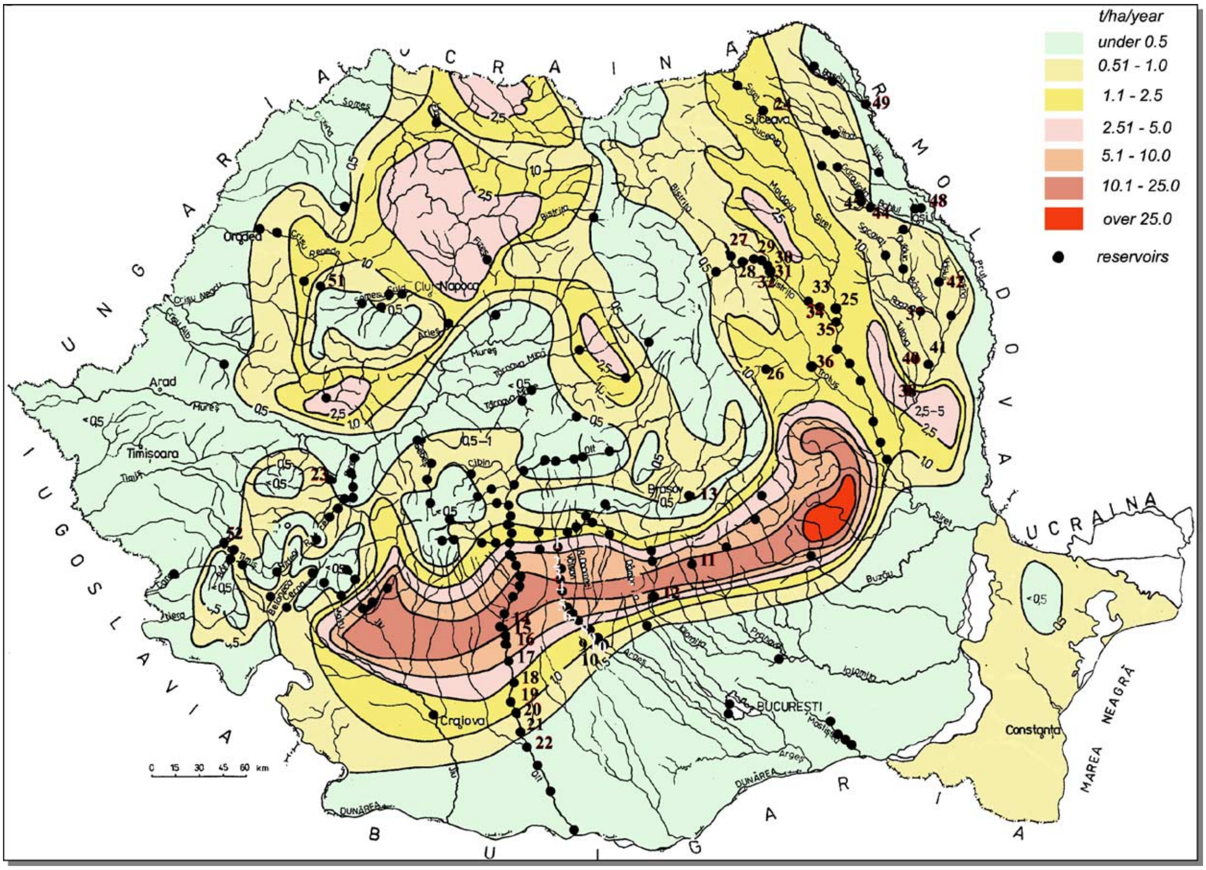

Fig. 8. Position of reservoirs in relation with the specific production of sediments. Numbers have correspondence in Table 2.

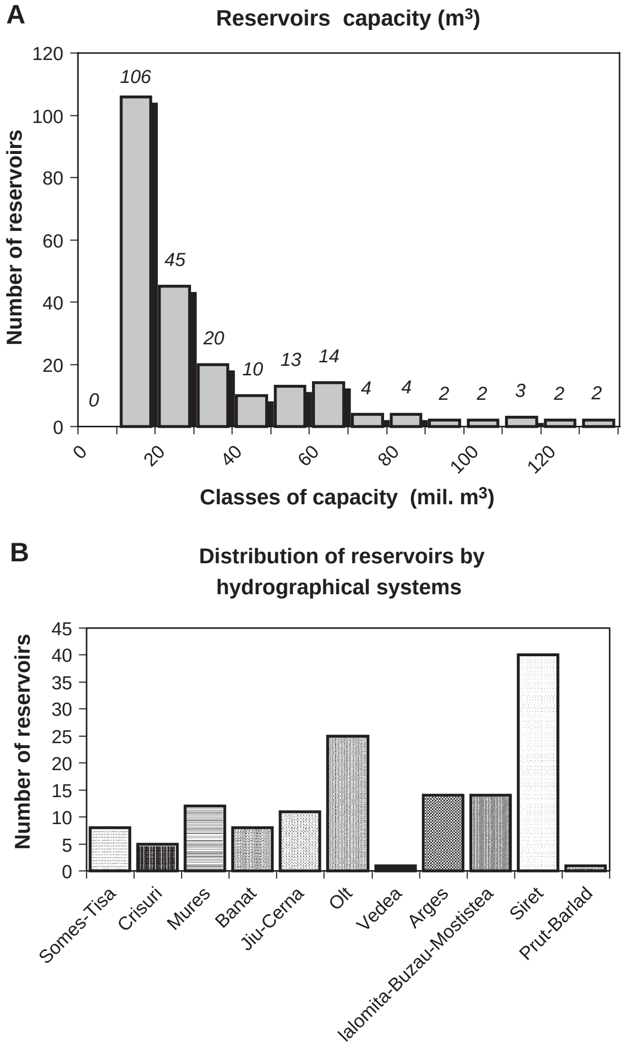

Fig. 9. The repartition of the dam reservoirs in Romania. (A) The histogram of the dam reservoir's capacity, under 140 millions mc. (B) The repartition of dam reservoirs on hydrographical systems.

simple reasoning: the larger a lacustrine basin, the more it can stock a large enough volume of sediments without affecting its functionality—and there are many examples in this direction. On the contrary, a lacustrine basin with a reduced capacity can become silted in a relatively short period, a few years or a few tens of years, even at relatively modest rates of sedimentation. The study of Dendy et al. (1973) for 1100 dam reservoirs in the USA indicated that the great majority of small lakes are becoming silted in < 30 years.

4.2. The silting rate

Some reservoirs in Romania have been functional for centuries (like those in the Banat or Metaliferi Mountains), but there are also lakes that became silted in a period of a few years. From the data we have at our disposal, we keep in mind a few observations of general character:

(i) in the whole country in an average period of 15 years, the reservoirs from the interior rivers have had depositions about 200 million m^3 of sediments (from which almost a half are only the reservoirs on the rivers Argeş and Olt), with a yearly installment of 13.4 million m^3, which represents 27% from the total supply of sediments, averaged and multiplied yearly;

(ii) the most important yearly rates of silting have been on the lakes from the sub-Carpathian area with easily erodible rocks, on the Argeş river: Piteşti 15.7%, Bascov 11.7%, Oieşti 9.5%, Cerbureni 7.3%, and Curtea de Argeş 5.3%; also Lake Galbeni on the Siret River, 10.6%;

(iii) average yearly rates of quick silting have been recorded also at the first lakes built on the Olt River: Govora 8,.7%, Rm. Vâlcea 5.63% and Dăeşti 4.90%; in the same category are included the lakes Pângăraţi on the Bistriţa River, 3.45%, or Pucioasa on the Ialomiţa River, 2.58%; and

(iv) a low rate of silting has been registered at the big reservoirs: Izvoru Muntelui at 0.03% and Vidraru at 0.04%, which ensure them with a millenary running, unless some incalculable situations occur.

Retaining as a basis of interpretation the necessary time for silting of 50% of the initial volume of every reservoir, 138 reservoirs from Romania, with an initial storage capacity between 1×10^6 m^3 and 1230×10^6 m^3, have been analysed. For these reservoirs, determinations have been made regarding the silting rate using various methods and different experts. Their repartition (depending on the major units of relief; Fig. 10) indicates that from the total number of analysed reservoirs only 44 are found in the mountain areas of the country, the region with the smallest rate of sediment production. The other lakes are placed in the regions of plateaus and hills, the Sub-Carpathians, piedmont and plain, all these being characterised through an accelerated rate of producing the sediments, except the plains.

In this general situation, the silting time of 50% of the reservoir's volume reflects the means of reply, through silting, of the drainage basins in comparison with the main morphodynamic regions of the analysed territory: it is reduced to < 100 years for the reservoirs found in the regions with the greatest production of sediments (sub-Carpathians, plateau and piedmont) and it is hundreds of years for the reservoirs situated in mountain and plain areas. In other words, only 57 reservoirs have enough silting time to justify the investment and important perturbation on the environment.

As a conclusion, the situation of the reservoirs silting from Romania is as follows:

(i) *very serious* for 15 reservoirs with average dimensions of 8 million m^3, all of them situated in the Sub-Carpathian area, one of the important sediment yields (over 500 tons/km^2/year); the silting time T50 of these reservoirs have values between 2 and 10 years;

(ii) *serious* for 30 reservoirs, with average capacities of 35 million mc, and the silting time T50 varies between 10 and 50 years. In this case, the reservoirs are also situated in the area of

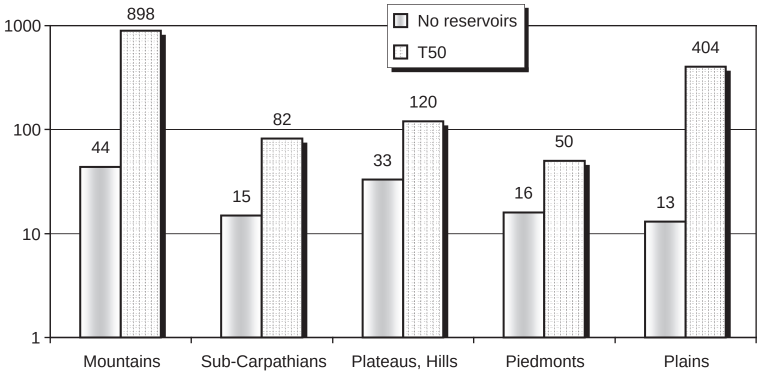

Fig. 10. Distribution of reservoir number and time of silting 50% of initial storage capacity in relation with main units of landforms.

Fig. 11. Izvoru Muntelei Reservoir. View on upstream sedimentation area after a period of emersion.

important specific sediment yield of over 250 tons/km^2/year, the case of the Olt, Argeş, Buzău and Bistriţa Rivers (Fig. 11), but also of the reservoirs in the Bârlad basin.

(iii) *difficult* for 13 reservoirs, with a silting time < 100 years and that are usually situated at about 200 tons/km^2/year (e.g., Rogojeşti on the Siret River, Izbiceni on the Olt River, Bacău on the Bistriţa River, Văliug on the Bârzava River).

Following this general image of the silting phenomenon in the reservoirs in Romania, we have to take into consideration the fact that in some arrangement projects priority it was given to the strict economic aspect and it was seriously eluded the knowledge the relief potential to reply in such an accelerated rate to sediment release and transport through the collector net. The reservoirs on the Argeş, Olt or Bistriţa Rivers are arranged in cascades. Important sums of money are spent in efforts made to desilt some important reservoirs for the functioning of the hydropower system, such as the Oieşti reservoir on the Argeş River and Pângăraţi on the Bistriţa River. On the other hand, it is admitted the fact that there haven't been done sediments keeping works in the source areas first and only after that the proper execution of the reservoir; in fact so many time the right order has been totally changed. The most notorious examples of this situation are the Bascov and Piteşti reservoirs: entirely silted in 2 years.

Acknowledgements

We would like to thank to Dr. P. Beyer and to Dr. R.A. Marston for substantial and constructive comments on preliminary draft of this paper. Also, special thanks to an anonymous referee for his helpful reviews.

References

Ciaglic, V., Vornicu, P., Stefan, A., Rudnic, I., Micu, I., 1973. Contribuţii la cunoaşterea fenomenului de colmatare a lacului de acumulare Pângaraţi. Hidrobiologia, 14.

Dascalescu, N., 2000. History of Dam Construction in Romania. Romanian National Committee on Large Dams, Bucharest, pp. 16–26.

Dendy, F.E., Champion, W.A., Wilson, R.B., 1973. Sedimentation survey in the United States. Man-made Lakes: Their Problem and Environmental Effects, Am. Geoph. Union, vol. 17, pp. 347–359 (Washington D.C.).

De Villiers, B.A., 1985. A multivariate statistical evaluation of a group of drainage basin variables: a South-Africa case study. First International Conference on Geomorphology, Manchester, UK. 134 pp.

Diaconu, C., 1971. Probleme ale scurgerii aluviunilor pe râurile din România. Studii de Hidrologie, vol. 30. INMH. 307 pp.

Dietrich, W.E., Dunne, T., 1978. Sediment budget for a small catchment in mountainous terrain. Z. Geomorphol. Suppl. (29), 191–206.

Gregory, K.J., Walling, D., 1976. Drainage basins. Forms and Processes. Ed. Arnold, London. 458 pp.

Griffiths, A.G., 1981. Some suspended sediment yields from South Island catchments, New Zealand. Water Resour. Bull. 17, 662–671.

Ichim, I., Rădoane, M., 1986. Efectul Barajelor în Dinamica Reliefului. Edit. Academiei, Bucureşti. 157 pp.

Ichim, I., Ursu, C., Rădoane, M., Dumitrescu, G., 1987. Cercetarea asistată de calculator a ierarhizării factorilor de control ai producţiei de aluviuni din bazine hidrografice mici. SC GGG, Ser. Geogr. 34, 17–28.

Ichim, I., Rădoane, M., Rădoane, N., Grasu, C., Cochior, C., 1994. Bugetul de aluviuni al bazinului râului Olteţ. Lucrările Sesiunii Stiinţifice Anuale. Institutul de Geografie, Bucureşti, pp. 17–29.

Ionescu, F., 1980. Consideraţii privind colmatarea acumulărilor. Hidrotehnica 25 (12), 272–277.

Jansson, B.M., 1982. Land erosion by water in different climates. UNGI Rapport, vol. 57. Uppsala Univ., Sweden. 141 pp.

Johnston, R.J., 1986. Multivariate Statistical Analysis in Geography. Longman, Londra. 276 pp.

Mociorniţa, C., Brateş, E., 1987. Unele aspecte privind scurgerea de aluviuni în suspensie în România. Hidrotehnica 32 (7), 11–19.

Moţoc, M., 1984. Participarea proceselor de eroziune şi a folosinţelor terenului la diferenţierea transportului de aluviuni în suspensie pe râurile din România. Bul. Inf. ASAS 13, 7–16.

Olariu, P., 1992. Impactul antropic asupra regimului scurgerii apei şi aluviunilor în bazinul hidrografic Siret. Lucr. IV, Simpozion PEA, pp. 121–130 (Piatra Neamţ).

Pavel, D., 1933. Plan Général d'Aménagement des Forces Hydrauliques en Roumanie. Nat. Roum. Pour l'étude de l'aménagement et de l'outil, des sources d'énérgie, vol. 58. 382 pp.

Pricop, A., Nicolau, A., Leu, D., 1988. Studiu privind influenţa unor factori cauzali asupra colmatării lacurilor de acumulare din bazinul hidrografic Bahlui. Lucr. Celui de al II-lea Simpozion PEA, pp. 114–120 (Piatra Neamţ).

Purnavel, Gh., 1999. Cercetări privind efectul lucrărilor de amenajare a formaţiunilor torenţiale, aflate în zona de influenţă ă excesivă a lacurilor de acumulare, asupra procesului de colmatare a acestora; cu referire la Podişul Central Moldovenesc. Rez. Tezei de doctorat, Universitatea Tehnică "Gh. Asachi" Iaşi.

Rădoane, N., 2002. Geomorfologia Bazinelor Hidrografice Mici. Editura Universităţii Suceava. 250 pp.

Romanian Committee for the Big Dams, 2000. Romanian National Committee on Large Dams. Bucharest. 351 pp.

Roşca, D., 1987. Cercetări complexe asupra colmatării lacurilor de acumulare. Lucr. Primului Simpozion P.E.A., pp. 63–70 (Piatra Neamţ).

Walling, D.E., 1983. The sediment delivery problem. J. Hydrol. 65, 209–237.

Williams, G.P., Wolman, M.G., 1984. Downstream Effects of Dams on Alluvial Rivers, U.S. Geol. Survey Professional Paper, vol. 1, 286. Washington, DC, 83 pp.

Zavati, V., Giurma, I., 1982. Cercetări privind colmatarea unor lacuri de acumulare din bazinul hidrografic Bahlui. Hidrotehnica 27 (2), 21–29.