SILTING EVALUATION ON GILĂU RESERVOIR USING G.I.S TECHNICS

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ABSTRACT. The observations and measurements realized along the years on Someşul Cald reservoirs cascade system confirm the existence of some specific risk elements (silting, reduction of characteristic volumes, changes of the aquatic environment etc.). The cooperation with the specialized units engaged in the administration of lakes ("Romanian Waters" National Administration – „Someş-Tisa" Water Branch, S. C. Hidroelectrica S.A. – Cluj Branch, S. C. „Someş" S.A. Cluj Water Company), has proved fruitful, as they made possible to supplement the information database. The application of digital analysis and G.I.S. technology in the data processing, made possible the setting of some important digital models and conclusions, as well as the establishment of the short-term tendencies of evolution of the phenomena and processes in the basins. The results obtained were applied to the activity performed by the fore mentioned institutions.

Key words: reservoir, silting, G.I.S. techniques and analysis, digital models.

Introduction

River reservoirs are affected by silting, phenomenon that reduces or determines the loss of some specific function (Bătuca & Jordaan, 2000).

The rate and intensity of reservoir's silting is generally determined by many factors, such as : the intensity and amplitude of sediments erosion and transport processes, the physical-geographical characteristics of the drainage basin, manner of land use, the conception of reservoir's design, exploitation regime, silting coefficient, abrasion phenomenon etc.

A reservoir has more silting area (Gottschalk, 1962, Giurma, 1997) like (fig. 1) :

- Dam siltings, with small particles, under 0,02 mm in diameter;
- Bed lake siltings; more or less uniform, with particles diameter of 0,02-0,05 mm;
- Lake's end siltings; representative of this area is the alluvial cone, with particles diameter of more than 0,03-0,05 mm;
- Upstream lake silting, in the afflux area.

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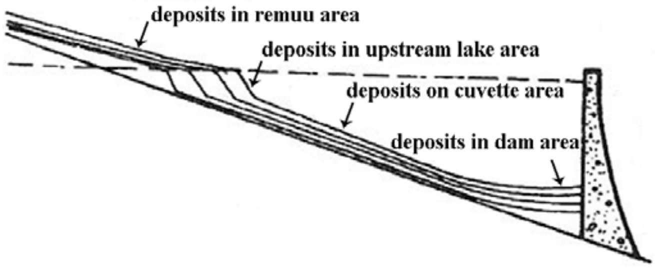

Fig. 1. Alluvium silting areas in a reservoir (after Giurma, 1997).

There appears a silts sorting phenomenon in a reservoir in time of silting process: the big ones deposit at the lake's end and the small ones near the dam or are taken by the water current downstream the dam. The silts deposit on the entire lake surface, but most of them deposit close to the dam, the sands deposit in the lake's central part. This alluvium sorting process appears also at the appearance and diffusion of flooding waters, but in reservoirs with high level variations, there appears a secondary silting moving phenomenon to the lake's end, to low lake levels, usually near the dam.If we ignore the local features, the complex silting phenomenon has more stages (Răzvan et al., 1974, Giurma, 1997):

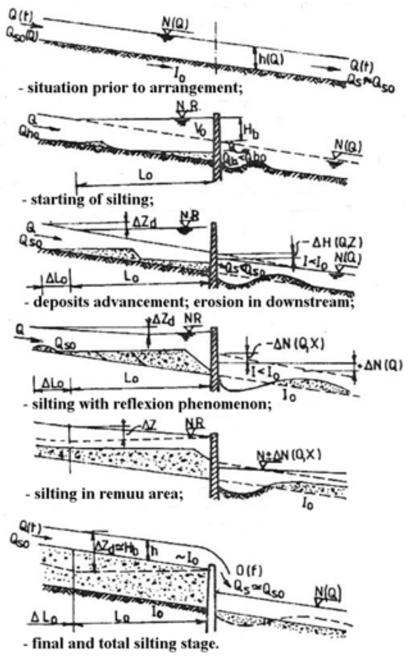

Fig. 2. Silting phenomenon stages (after Giurma, 1997)

– It is supposed that in the period before the lake's existence, the water course was morphologically stabile, and the transport phenomenon is determined by the thalweg's average slope, by the accidental distribution of discharge and by the level's variation (fig. 2);

- The initial phase, after the lake's filling with water, is defined by the normal retention level (NNR) and by the initial length of remuu curve; the silting process begins at the lake's end, where the biggest particles decant to form a bank; the floating particles decant along the bank following their hydraulic dimensions;

– Bottom alluvium front advances over the floating alluvium front, expanding itself over the remuu area, forming level aggradations in free area; in this stage there appears erosion downstream the lake for a long distance;

– Silting phenomenon continues

till, after a certain number of hydrological cycles, the floating alluvium front reaches the dam, appearing a reflection phenomenon; after that, the silting process quickens;

– The initial reservoir's volume till NNR is practically silted, and the alluvia decant partially in the remuu area, partially downstream the dam;

– In a phenomenon's final theoretical stage, the silting develops so the initial slope reappears; the lake's functions are practically cancelled, and the alluvia regime becomes the same as the one before the dam's construction.

The silting rate can be estimated if we take into account some factors as : liquid and solid annual discharge volume, reservoir's volume, the regime of reservoir's exploitation, alluvia physical-mechanical characteristics, the quantity of lake retained alluvia etc.

In cascade systems, such as the Someşul Cald one, that continue with the Someşul Mic, the phenomenon's evolution diverse from a reservoir to another, according to : their position in the system, the basin's petrographic constitution, the lake's bed morphology and dimensions, and the liquid and silting discharge volume. With a full capacity of re than ore330 million m^3, the four reservoirs of the Someşul Cald Valley (Fântânele, Tarniţa, Someşul Cald and Gilău) represent an important water reserve capitalized energetically and supplying water for an extensive area and a large number of inhabitants (more than 600,000).

Their location toward the outskirts of the northern part of Apuseni Mountains (in the area of outcrop of the sedimentary rocks) determined the appearance of numerous elements of risks in the optimum exploitation of these reservoirs (fig. 3).

If the presence of the anthropogenic flows (especially the tourist flows) has determined the qualitative degradation of these waters, the sedimentary rocks from the north-eastern part of the drainage basin has favored a high rate of sedimentation.

The characteristic volumes of the reservoirs provide information about the complex functions concerning the lake units (Csermak et al., 1970), table 1.

Gilău Lake, is the first built (1972) and the smallest one. It has also a complex function, related to: with Tarniţa reservoir, the supply of water for an important network of settlements and economic units placed downstream – Cluj-Napoca City (population and industry), the olds mining regions of Căpuş and Aghireşu, the commune of Apahida and other settlements of Someşul Mic flood plain, the towns of Gherla and Dej; the rectification of the discharges coming from the upstream hydropower stations; the production of electricity in the hydropower station located at the base of the dam; the function of attenuation of flash-floods is insignificant due to its small characteristic volume (Table 1).

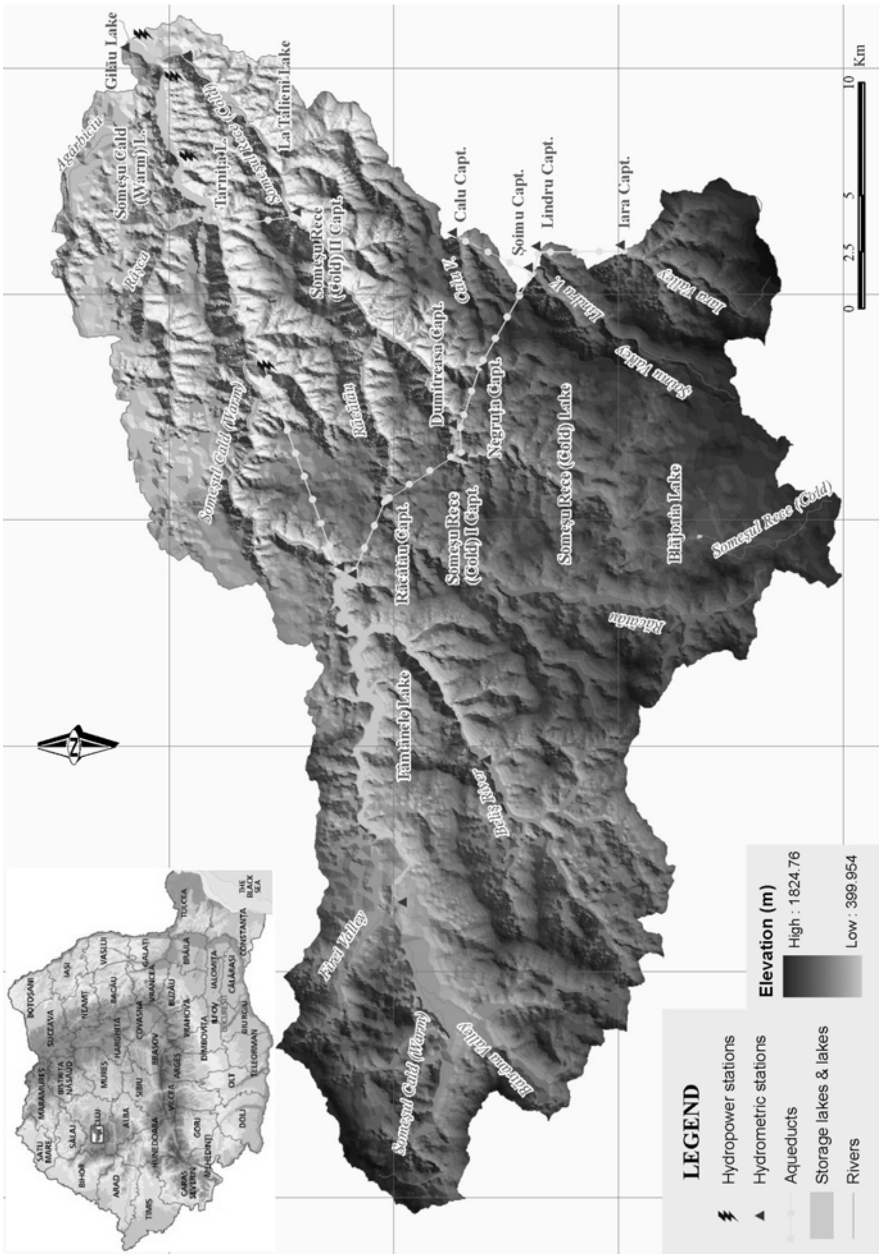

Fig. 3. General map of the drainage basin of the reservoirs
of the Someşul Cald Valley.

Table 1. Characteristic volumes of the reservoirs of the Someşul Cald Valley, according to the latest bathymetrical surveys

No.	Lake / Year of survey	Characteristic volumes (mil. m^3)					
		Global	Raw	Attenuation	Available	Spare	Dead
1	Fântânele / 2000	244.69	207.59	37	186.93	10.17	10.5
2	Tarniţa / 2001	75.25	68.08	6.9	13.79	39.08	5.62
3	Someşu Cald / 1993	8.45	6.45	1.99	0.86	3.41	2.18
4	Gilău / 2005	3.56	2.45	1.12	0.61	1.4	0.44

2. Methods

Compared to the previous measurements (before 1992), performed with levels and theodolites for the operation of topometry, and with a simple manual sounding line for the bathymetry, the recent technical devices facilitated the development of campaigns with precise measurements.

In this purpose, GPS Trimble and Magellan terminals were used at the last measurements for the execution of topometry, together with total station in the sectors with consistent tree tops. For bathymetry, simple sounders or sounding winches were used in the case of low depths (upstream extremity). In the others sectors of the reservoir it managed to draw profiles using the ultrasonic sounder. In the shallow areas, the profiles were doubled by classic measurements.

The information was centralized and processed in digital mode, using the Microsoft Office, the ESRI ArcView 3.x and ArcGIS/ArcINFO 9.x products.

3. Silting rate of the characteristic volumes

Gilău reservoir represents the most silted up lake unit among the four lakes of the system. Following the data from the table 2, we can distinguish two stages in the evolution of the phenomenon, each having distinct features.

The first stage corresponds to the period 1972 - 1983, before the creation of Someşul Cald Lake. This stage is characterized by high percents of the decrease of all the characteristic volumes, the values ranging between 8.48 and 13.08 % for the global volume, 8.34 and 16.89 % for the raw volume, 2.17 and 11.06 % for the attenuation volume, 4 – 5 % for the available volume, 6,44 and 17,83 % for the spare volume and 18,24 - 26,42 % for the dead volume. The same situation is met for the annual average rate of silting.

Table 2. The dynamics of characteristic volumes due to the silting phenomenon.

Time interval	Global volume				Raw volume				Attenuation volume			
	Silted		Yearly aver. rate		Silted		Yearly aver. rate		Silted		Yearly aver. rate	
	(mil. m^3)	%	(mil. m^3)	%	(mil. m^3)	%	(mil. m^3)	%	(mil. m^3)	%	(mil. m^3)	%
1972-1976	0.700	**13.08**	0.175	3.27	0.670	**16.89**	0.168	4.22	0.030	**2.17**	0.008	0.54
1976-1983	0.454	**8.48**	0.065	1.21	0.331	**8.34**	0.047	1.19	0.153	**11.06**	0.022	1.58
1983-1992	0.130	**2.43**	0.014	0.27	0.097	**2.44**	0.011	0.27	0.003	**0.22**	0.000	0.02
1992-1995	-0.040	**0.73**	-0.010	0.24	-0.030	**0.66**	-0.010	0.22	-0.010	**0.94**	-0.004	0.31
1995-1999	0.189	**4.60**	0.047	1.15	0.180	**6.21**	0.045	1.55	0.009	**0.74**	0.002	0.18
1999-2005	0.351	**8.96**	0.058	1.49	0.265	**9.76**	0.044	1.63	0.086	**7.16**	0.014	1.19
1972-2005	1.784	**38.28**	0.054	1.01	1.513	**44.30**	0.046	1.16	0.271	**22.29**	0.008	0.59

Time interval	Available volume				Spare volume				Dead volume			
	Silted		Yearly aver. rate		Silted		Yearly aver. rate		Silted		Yearly aver. rate	
	(mil. m^3)	%	(mil. m^3)	%	(mil. m^3)	%	(mil. m^3)	%	(mil. m^3)	%	(mil. m^3)	%
1972-1976	0.039	**4.74**	0.010	1.18	0.382	**17.83**	0.096	4.46	0.265	**26.42**	0.066	6.60
1976-1983	-0.040	**4.38**	0.005	0.62	0.138	**6.44**	0.020	0.92	0.183	**18.24**	0.026	2.60
1983-1992	0.027	**3.28**	0.003	0.36	0.058	**2.71**	0.006	0.30	0.042	**4.19**	0.005	0.46
1992-1995	-0.010	**0.85**	-0.002	0.28	-0.040	**1.73**	-0.010	0.58	0.018	**1.79**	0.006	0.60
1995-1999	0.148	**18.50**	0.037	4.63	0.093	**5.81**	0.023	1.45	-0.061	**12.30**	-0.015	3.08
1999-2005	0.036	**5.53**	0.006	0.92	0.109	**7.23**	0.018	1.20	0.120	**21.58**	0.020	3.60
1972-2005	0.200	**37.28**	0.006	0.76	0.740	**41.75**	0.002	1.05	0.567	**84.52**	0.017	1.71

This less favorable dynamics for the reservoir is due to the supply of alluvia from both Someşul Cald, in overwhelming proportion from the Agârbiciu basin, and from Someşul Rece. It is obvious the fact that during this period the main role in the silting phenomenon was played by the first river, aspect which is also proved by the silting evolution of Gilau Lake after the construction of the Someşul Cald lake dam.

A part of this period was studied in detail by Aniţan et al., 1977 including the granulometric analysis of the sediments laid down.

The second stage is identified with the period 1983 - 2005, when the evolution of the silting phenomenon was very slow in the beginning of the period, but complicated towards its end. The percents of the volumes reduction no longer exceeded the value of 4 % except for the case of the dead volume (4.19). The annual average rate of silting was also kept within limits compared to the previous stage, without exceeding 1.5 %. In the last part of the period, the intensification and growing frequency of climatic and hydric extreme phenomena led to an overturn of the situation. After several great flashfloods, of which a catastrophic one on Someşul Rece, in December 1995, the percents of reduction of the characteristic volumes grew very much, and so did the annual average rate of silting. They varied between 4.60 and 21.58 for volumes, and between 1.15 and 3.60, for the annual average rate of silting, with the single exception of the attenuation volume between 1995 and 1999.

Generally, the silting degree of Gilău reservoir is very advanced: 22.29 % for the attenuation volume, 37.28 % for the available volume, between 38 and 45 % for the global, spare and raw volumes and 84.52 % for the dead volume.

The risks induced by the silting of reservoir have become manifest by: the increased frequency of floods in the upstream and downstream sectors; the reduction of characteristic volumes, especially the available volume, with important implications concerning the uses (supply of water, production of energy, the flash-flood attenuation etc); the jam of the dam evacuators; the development of underwater vegetation playing a part in the acceleration of the silting phenomenon and in the negative effects on the quality of water; the acceleration of river-bed degradation in the sector dowstream from the dams etc.

From the point of view of the economic effect, the silting of the lakes, in different stages, can be compared with the events at the dams (Roşu, Corina & Creţu, 1998).

Thus, the reduction of the reservoir available volume with less than 50 % throughout the entire designed life of the building can be considered an *incident*. The reduction with 50-75 % of the available volume during a period shorter than the designed life of the building, which leads to the temporary obturation of the capture front can be assimilated with an *accident* - type event. The reservoirs which have functions like the supply with water of communities, irrigations, leisure, fish farming, and the available volume has been reduced with about 75-90 % during a shorter period than the designed life of the building, are considered to be affected to a level equivalent to the *destruction of the dams*.

According to the silting rate, the Gilău reservoir can be framed in one of the three above categories, because the silting phenomenon affects a little the available volume slice (table 2).

The reduction of the lake specific capacity with 37.28 % can be considered, by comparison, an *incident*, because it affects in a sensitive way the hydropower and water supply functions. Considering that the tributary flow in the lake becomes 0 m^3/s, the lake available volume would be enough for a little more than three hours for the functioning of the hydropower station and for about 49 hours for the functioning of Gilău water treatment station, which provides water for 600,000 inhabitants from the neighbouring zone.

4. The map of decanted sediments thickness

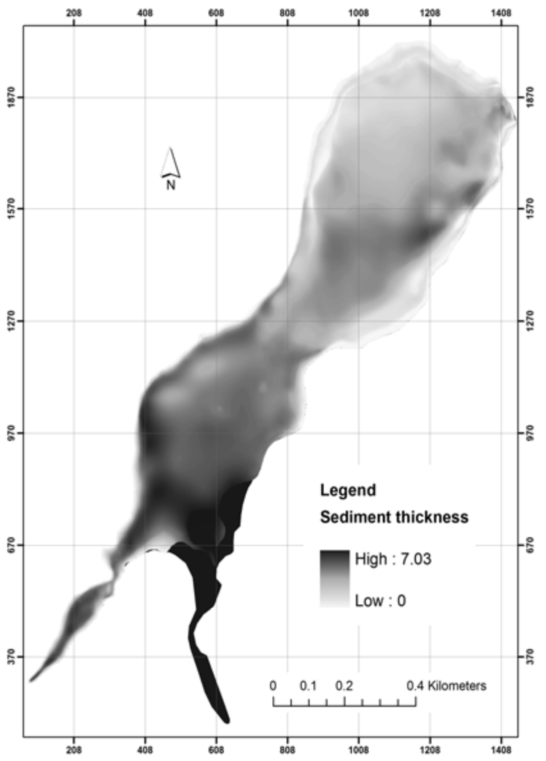

Fig. 4. The map of sediments thickness in Gilău reservoir between the first takings (1969) and 2005).

The representation of decanted sediments thickness digital model is one of the most precise imagine of lacustrine silting modifications (Şerban and Bătinaş, 2011).

To exemplify this affirmation will use the Gilău reservoir model (Fig. 4). In this case, the lake's bed transformations between the two bathymetric takings (one made by the engineer – 1969 - and one by the "Someş-Tisa" Water Basin Administration specialists - 2005) are spectacular.

The working stages imply the following operations :

- In the ArcMap module we open a project named, for example, *gisgilau1969-2005.mxd;*

– We upload the following themes : lacustrine model's grid from the first takings (*demgil69*); lacustrine model's grid from the last takings (*demgil05*); we can also upload also the outlines of the two grids, to overlap and observe the shore's line modification;

- From *Spatial Analyst* toolbar open the *Raster Calculation* function, and upload there the *demgil05* grid (double click on *Layers* window); click on the "-" (minus) button, and after that upload in same way the *demdil69* grid;

To generate the silting grid and decanted sediments thickness grid, click on *Evaluate* button;

Because the grid that appears (*Calculation*) is placed on Temporary Files Directory (C:\Users\.....\AppData\Local\Temp), we will copy it in our directory GISGilău1969-2005 using ArcCatalog or other program that accesses this type of files (Total Commander, windows Explorer) and we'll rename it in ArcCatalog, for example *sediment*;

- In the GIS application *gisgilă*u1969-2005.*mxd,* the *Calculation* grid placed in Temporary Source will be deleted and we'll upload a new theme (*sediment*) from the working directory;

- We choose a chromatic scale that will best express the extreme silting values (Fig. 4).

In the *sediment* grid's legend, the dark color band will present the high decanted alluvia volumes, usually at the confluence of tributaries with the lake's water, or in areas with high degradation shore rates, where the sediments are reshuffled nearby or in bottom layers. The light color band presents small sediments thickness, and appears at the lake's bed and near the dam, where only the small alluvia reach, such as clay and mud.

5. Changes in lake basins morphology

The use of GPS and echo sounder for the bathymetric measurements and the GIS techniques for the processing of the information provided, made possible the creation of 3D models, allowing the determination of the changes on the space of the lake basin (Kondratyev & Filatov, 1999 and Şerban et al., 2005).

For the Gilău reservoir the repartition of the sediments on the basin bed is different, because of the low depths, the smaller capacities, the consistent alluvial share and the different water flow - buffer lake,(fig. 5).

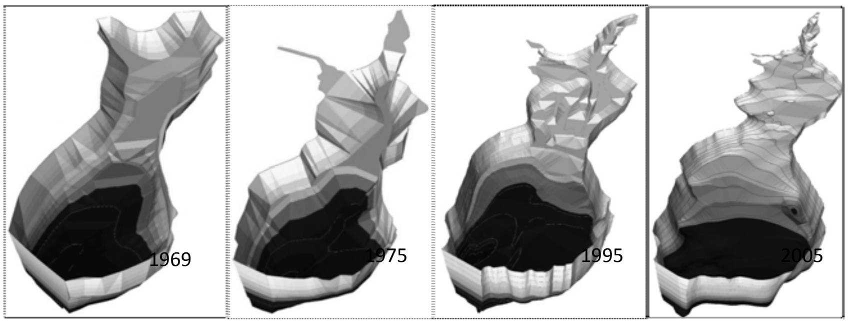

Fig. 4. 3D scenes and stages of evolution of Gilău reservoir basin.

The consistent alluvial share (maximum in the hydrographic basin, as seen above regarding the silting rate assessment), has been scattered in another way than the natural one, due to the water flows coming from the upstream Someşul Cald hydro-power station. The clayish sediments were reshuffled in the shape of alluvial banks, alluvial bars and longitudinal channels, deviations of thalwegs and alluvial terraces. A part of them was present also in the upper sector of the lake basin, in the calm periods between evacuations in the same configuration (Şerban & Alexe, 2006).

In the Gilău reservoir, the geological factor has mostly influenced the distribution of the sediments in the basin space. The stratum of Upper Cretaceous Sandstones which crosses the lake in the median zone operates as a threshold and causes a narrowing and the basin partition into two sectors, each of these sectors having an independent alluvial evolution, fig. 4.

The discrepancy concerning the silting of the two sectors appears as far back as the first years after the creation of the lake. In the upper sector of the basin, a narrowing of the former flood plain of Someşul Mic river took place in the first stage, due to the effect of the two-sided alluvial transport (Someşul Cald and Someşul Rece). Subsequently it disappears as a morphological unit (in the year 1977) to be substituted by a combination of the two rivers alluvial cones. After the year 1983, the alluvial share from the Someşul Cald becomes neglectable and the evolution of the cone ceases, while the one of Someşul Rece evolves as a small delta and the thalweg is pushed towards the left slope.

Conclusions

Less optimistic is the forecast for the Gilău lake. Especially in this case, the silting of the dead volume part can lead to the jam of the bottom-discharge and, also, to other drawbacks in the functioning of the installations. Also, the higher frequency of climatic and hydrological risk phenomena of the last decade raises serious issues for the two downstream reservoirs, as their basin configuration and the trends of their volumes react fast to the pulsations generated by flash-floods.

In the present conditions of sedimentation, the "life" of available volume can be estimated to around 90 years for Gilău reservoir.

The silting rate may be amplified by the presence of some natural unbalances or by negative intervention of the human factor. By positive interventions, man can attenuate this phenomenon. The actions should be directed as to decrease the alluvial transport toward the reservoirs, by building small dams on the tributaries. The newly created reservoirs would collect the alluvial flow and the fill of the basin would be easier than in the case of the large reservoirs. Also, they might be used for other purposes (tourism, fishing etc).

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