RESEARCH ON SILTING AND DESILTING OF RESERVOIRS (ARTIFICIAL LAKES)

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Silting lakes as a process itself was inferred long time ago, but the proportions, dynamics and control means were not carefully approached, the negative consequences arisen in the practice of lake exploitation providing this.

The goal of research on silting and desilting lakes should aim to find forecasting methods - planning required, establish mitigation measures of silting lakes in order to increase their operating period to designed parameters and not least desilting of lakes.

This paper aims to present a forecasting model of the phenomenon of silting lakes used for finding methods to prevent silting of reservoirs and desilting measures.

Keywords: silting (clogging), desilting, forecasting methods, mitigation measures of silting (clogging)

1. Introduction

In designing reservoirs, silting problem plays an important role because their operating mode and period depend on this phenomenon. Annual sediment load in a lake is 2-3 or even 4 times higher than the one required by design (Dos MTC '69). Taking into account the limits of current technology, it should be recognized that the final filling of lakes with sediments is inevitable, but it must be treated very seriously in designing activity, in order to ensure the functioning of lakes as long as possible (Benedict CP others, 1973), by providing preventive measures of silting, but also measures of desilting.

The approach of the subject of reservoir-silting has been achieved both nationally and internationally in diverse professional works, theses, and articles in different conferences. The general conclusion that can be drawn is that silting is a complex process which begins when the lake starts operating and practical ends when the lake is off. To understand this process, it has to start from the sources of the deposited sediments in a lake (the lake water catchment basin and the

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hydrographic network) and it must take into account the two forms of solid contribution, namely: the dragged solid flow and the suspended solid flow.

Because clogging of artificial lakes reduces their capacity, and hence their operating period, studies and appropriate measures are needed to reduce the intensity of this process. In our country these studies must be a current problem, imposed by the large number of lakes affected by this phenomenon.

Clogging lakes must be a permanent concern of the specialized groups in the field of water management, river basin planning complex, environment protection etc.

The goal of research on silting and desilting of reservoirs (artificial lakes) should aim to find forecasting methods-planning required (to calculate the capacity reserved for sediments in a lake from its opening till the end of its working period), to establish mitigation measures of silting lakes to increase their working period to the designed parameters and not least desilting lakes, which is very expensive[1].

Another problem frequently approached in studies is the quantitative evaluation of damage due to clogging, which is extremely difficult. In the specialized literature there are still some global data, which give an idea of the order of magnitude of such damage. The information related to the specific costs of reservoirs achievement is very interesting on the course of time. It can be noticed a gradual increase of their amount in time. This is due to general increase in prices, but also because the appropriate sites for reservoirs were partially depleted. So, all existing reservoirs should be protected by a series of measures.

This paper aims for a particular case of a lake, to present a forecasting model of the phenomenon of silting lakes, model which can be used later for finding methods and measures to prevent reservoir-silting and also desilting measures.

2. Zigoneni lake (accumulation)

Zigoneni lake, the fourth lake situated downstream of Vidraru lake, is located on the Arges River approx. 3.5 km downstream of the confluence with the Valley Sasu brook, village Zigoneni, commune Baiculesti[2].

Zigoneni lake (accumulation) has as main function producing electricity (15.40 MW installed capacity, installed flow 90 m^3/s).

The frontal dam consists of an outlet structure type spillway, multiple stage, with a flap, segment valves and a buffer of retention which is provided with two lateral dams for fixing on the shores. The dam is made from a massive concrete invert in which there are inserted right shore abutment, left shore abutment and two intermediate cells with a width of 2.0 m. The dam headroom is

27.00 m and the length of the spillway dam is 20.60 m (photo 1). The crest of a wave level is 395.00 mdM and the foundation level is 366.30 mdM.


Photo. 1. Zigoneni – The frontal dam.


Photo. 2. Zigoneni lake (accumulation).

The dam has a flap 16.00 x 3.00 m with a hinge at level 389.80mdM and 3 segment valves 4.00 x 4.00 m with weir still at level 377.50 mdM and a lateral outlet structure (2 section galleries 2.50 x 2.00 m, located on the left shore of the dam).

The maximum calculation flow with an exceeding probability of 1%, is Q1% = 470.00 m^3/s and the maximum test flow, with an exceeding probability of 1 ‰ is ‰ Q1 = 840.00 m^3/s.

The lake has a total volume of 13,300 million cubic meters (photo 2). The normal top-water level is at 393.00 mdM, and the lowest operating level is at 384.60 mdM. The lake has a total surface of 182 ha NNR, a length of 3.10 km and a width of 0.70 km.


Photo. 3. Zigoneni lake (accumulation).


Photo. 4. The tail of Zigoneni lake.

3. The clogged volume determination

The clogged volume determination for Zigoneni Lake is based on topo-bathymetric measurements. These measurements are performed every two years.

The measuring techniques of water depth can be classified into: techniques using mechanical measuring equipment and techniques using electronic measuring equipment.

The depth measurement techniques using mechanical equipment provide data with a very good precision when measuring small depths, about 10 – 15 m. Above these depth values the accuracy decrease significantly. Accuracy is very good for areas in which the water bottom consists of hard sediments, so that the used water gauges do not penetrate deeply these sediments. Accuracy is strongly affected if the composition of deposited sediments on the bottom is low, test probes could penetrate them on distances which can vary from few centimeters to 2.1 meters, thus altering the real value of the measurement. The measurement methods which apply the depth measurement techniques using mechanical equipment are: sounding pole and sounding disk [3].

The depth measurement techniques using electronic equipment provide data with a very good precision without taking into account the size of the measured depth. Accuracy is very good no matter how the consistency of bottom deposited sediment is, due to the possibility of coupling with calculation electronic equipment which can minimize all types of errors. The measurement methods which apply the depth measurement techniques using electronic equipment are: acoustic sounding method (echo sounding) and image processing method provided by the sensors installed on geostationary satellites (mapping water depths from space).

For Zigoneni lake, until 2009, depth was measured using the sounding disk method, and since 2009 it has been used the echo sounding method (sonar). Topo-bathymetric measurements are used for the live storage determination. The difference between this and the initial volume represents the clogged volume (Fig. 1, Table I).

Table 1

The clogged volume determination[4]

Year	Lake volume (m^3)	Volume differences (m^3)	Clogged volume (m^3)
1978	13,300,000.000	0.000	0
1996	9,804,357.000	3,495,643.000	3,495,643.000
1999	9,392,544.000	411,813.000	3,907,456.000
2001	9,299,314.000	93,230.000	4,000,686.000
2003	9,053,711.000	245,603.000	4,246,289.000
2005	8,075,155.000	978,556.000	5,224,845.000
2007	7,732,067.000	343,088.000	5,567,933.000
2009	7,596,137.000	135,930.000	5,703,863.000
2011	7,418,436.980	177,700.020	5,881,563.020

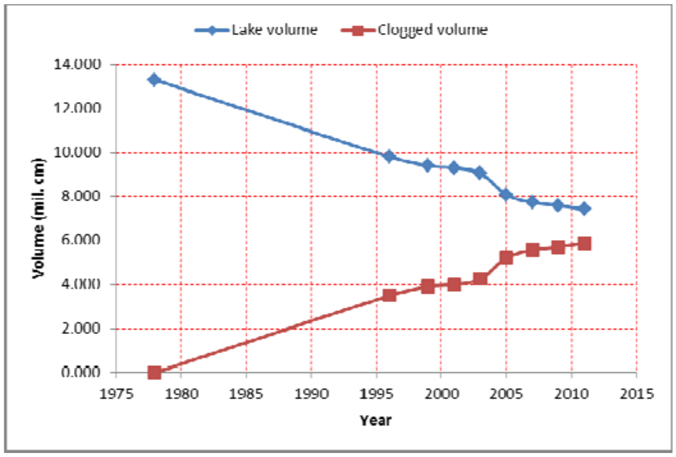

Fig.1. The evolution of Zigoneni lake clogging.

Comparatively, using bathymetric measurements, in Fig. 2 it is shown the evolution of clogging between 2009 and 2011 for two transversal profiles through the lake.

4. The clogging degree forecasting

The calculation model of silting forecast (determining the volume of the transported alluvial material in the lake) was performed using HEC-RAS computer program. HEC-RAS, developed by the U.S. Army Corps of Engineers, Hydrologic Engineering Center, is one of the most known and used packages in the world, regarding the analysis of hydrographical systems[5].

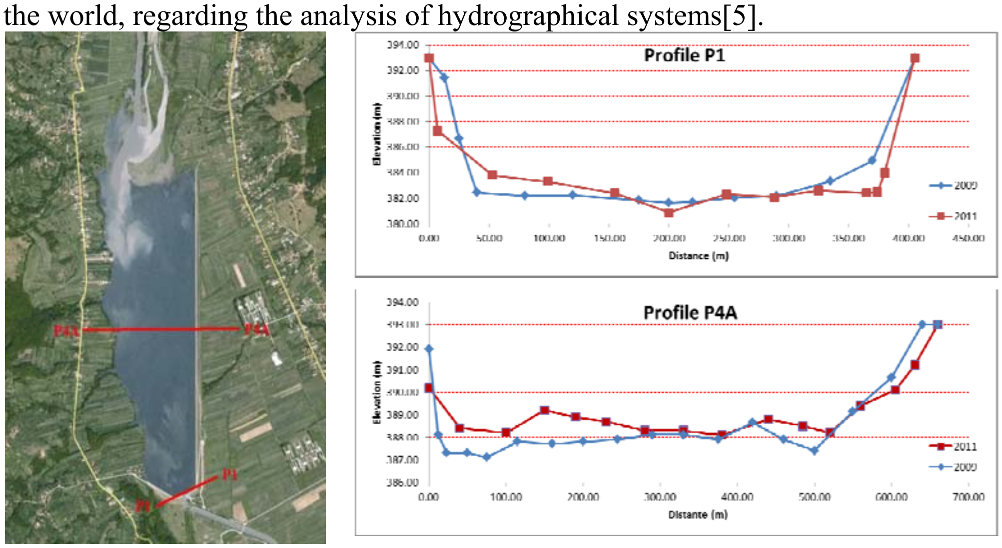

Fig. 2. Profiles through Zigoneni lake to underline the phenomenon of clogging between 2009 and 2011.

The program, which applies one-dimensional flow model with the free surface, can calculate this surface on permanent and non-permanent move, gradually varied on natural rivers or built channels, and also calculate, using input data the volume of transported and deposited sediments.

For the calculation of sediment transport, the HEC-RAS must first solve the flow in that river section. Like other models, the HEC-RAS uses a simplified hydrodynamic model, a common approach used in various sediment transport models. Thus, HEC-RAS uses the quasi-permanent movement hypothesis that estimates the flow hydrograph with a series of discrete profiles for which the flow is constant. Thus, the profiles in which the flow is permanent are easier to deploy and their rolling is much faster.

HEC-RAS for modeling sediments transport solves the Exner equation (sediment continuity equation):

$$\left(1-\lambda_p\right)B\frac{\partial\eta}{\partial t}=-\frac{\partial Q_s}{\partial x} \tag{1}$$

where: B – channel width, η – chanel share, λ_p – bed porosity, t – time, x –distance, Q_s – transported solid flow[6].

Equation (1) specifies that changing of the transported solid flow in a control volume, is the difference between the entered solid flow and the one emerged from that volume. The equation is solved by calculating the transport capacity (of transported solid flow) through a control volume associated with each cross section of calculation. This transported solid flow is compared with the solid flow entering the control volume. If the transported solid flow is bigger than the entered one, then there is a lack of sediments in the control volume, deficit which is replenished by the riverbed erosion. If there is a surplus of transported solid flow, then the excess of sediment is deposited.

Following the recording and reproduction of silting phenomenon that occurs naturally in the analyzed site, the calculation model used to perform reservoir-silting forecast is based on data regarding the annual volumes of reservoir-silting and the hydrological data of accumulation (flows, exploitation system, granulometric keys of transported alluvial material etc.).

To reproduce the silting phenomenon of Zigoneni Lake, the flow model will cover the lake itself, and the tail race from CHE Noapteş, the upstream accumulation from CHE Zigoneni. The tail race, an excavation channel with trapezoidal section has a length of 2063.70 m, and a slope of 0.243‰. Besides this trail race, the natural bed of the Arges river will be modeled too.

The flow modeling on the two rivers will be realized under the quasi-non-permanent movement regime, for the flow with an exceeding probability of 1%, the flow model calibration being based on the roughness of the two beds.

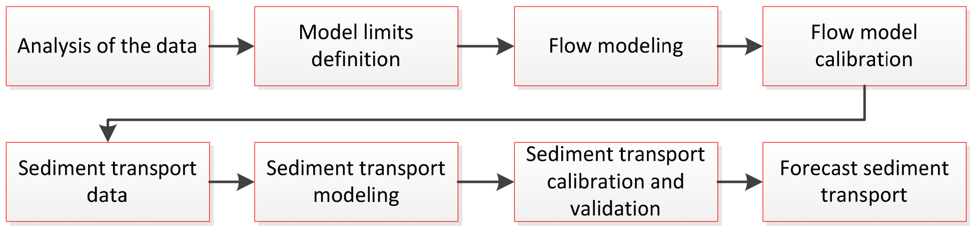

Fig. 3. Sediment transport modeling for Zigoneni lake clogging forecasting.

The sediment transport on the two rivers is realized starting from the grading curves of the transported material being in suspension. Regarding the transport of suspended solid particles, these are distributed throughout the mass current, their keeping in suspension being achieved by the effect of the turbulent velocity pulsations.

In general, fine particles which are small components of the riverbed are carried in suspension. Therefore, the solid suspension flow depends on the available flow from the water current rather than on the transport capacity of the liquid current. In most cases this transport is unsaturated.

Obtaining formulas for suspended solid flow calculation requires knowledge of both speed and concentration. Regarding the vertical distribution of concentration there are mentioned the following theories: the theory of turbulent diffusion, the energetic theory and the gravitational theory[7].

The sediment transport calibration will be based on measured data regarding the clogged volume of Zigoneni Lake. Once calibrated and validated this model can be then applied to forecast future volumes of transported sediment material which will be deposited in the lake

Using this calculation model provides (in conditions of the calculation model calibration) the forecasting of the alluvial material quantity transported and deposited in the lake.

5. Conclusions

The sediment transport modeling is a difficult process because the data used to forecast this transport and riverbed changes are extremely sensitive to a wide range of physical parameters. However, once calibrated, a forecasting model of sediment transport can provide on a long-term the regional trends and it can be used as a decision and planning tool.

This model will be applied in a report of a doctoral thesis regarding the reproduction and forecasting of the clogging phenomenon of an artificial lake.

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