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BATHYMETRIC SURVEYS OF SHPILJE RESERVOIR

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Abstract. *Periodic bathymetric surveys are carried out to define quantity of sedimented material in reservoirs, as well as to determine the areas most endangered by the silting process. Such surveys in the Republic of Macedonia were started as an obligatory and regular practice in the seventies of the last century, immediately after the formation of the larger artificial lakes. These were carried out for almost all reservoirs in the country and it can be said that there is already a sufficient amount of data on some of them that can serve as a basis for high quality analyses of the silting trend of the reservoirs and of the extent to which erosion is affecting the basin area. This paper provides a review of the results from the latest field surveys and analyses of changes in the configuration of the Shpilje reservoir bottom, carried out in the period 2014 to 2016.*

Key words: *bathymetric surveys, reservoir volume, silting with sediments.*

1. INTRODUCTION

Intensive construction of dams in the Republic of Macedonia and creation of reservoirs for different purposes started in the second half of the last century. Up till now, 23 large dams and over 120 small dams have been built in the territory of the country. With the very formation of the reservoirs, there started systematic periodic hydrographic surveys for the purpose of defining the sedimentation trend, i.e., changes in the capacity of the reservoirs due to sedimentation of deposits. In addition, the spatial distribution and the effectiveness of the reservoirs in keeping the sediments were analyzed. Based on such analyses, instructions were given for protection against erosion in the reservoir basin areas.

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Turbulent social changes in the territory of former Yugoslavia caused a slowdown in monitoring of the sedimentation in the reservoirs of the Republic of Macedonia so that hydrographic, i.e., bathymetric surveys were not at all carried out in a period of about 20 years. Data for reservoirs are often limited due to the expense and time required for their acquisition via field survey (Revenga et al., 2005; Zhang et al., 2016; Palanques et al., 2014; Vörösmarty et al., 2001).

Bathymetric surveys can help to manage water and make decisions, especially when natural hazards such as droughts and floods occur (Ayana et al., 2015; Ortt et al., 2000; Gao, 2009)

To continue with the positive practice of monitoring the sedimentation process, efforts have been made for the last few years to resume surveys of reservoirs throughout the country. Among the first such surveys was the one done for the Shpilje reservoir or Debar Lake. Some of the results from the performed analyses are given further in this paper.

2. Survey of the Bottom Topography of Shpilje Reservoir

Debar Lake or Shpilje reservoir represents an artificial lake located in the west part of Macedonia, south of the town of Debar, in the vicinity of the Macedonian-Albanian border. The lake covers an area of 13.2 km^2; it is 92 m deep and is situated at an altitude of 580m above the sea level. It was created with the construction of a 102 m high dam located at the merging point of the Crn Drim River and the Radika River. This dam was constructed in the period from 1966 to 1968. With its total capacity of 543 x 106 m^3 of accumulated water, Debar Lake has more water than any other individual artificial lake in Macedonia. Its basic purpose is production of electric power, irrigation, sport and recreation and lately, commercial fish breeding.

Fig. 1 Location of the Shpilje reservoir

The first hydrographic surveys of the Shpilje reservoir after it had been put into operation were carried out in 1986. Based on these surveys, a study was elaborated on the changes of the reservoir bottom and quantity of deposited sediments for the period starting with its putting into operation. An emphasis was also put on the most exposed zones of the reservoir regarding silting intensity and corresponding measures for protection were proposed. Since then, no surveys were done until 2014 when these were resumed. Surveys were carried out in the period from 16th to 25th June, 2014. For these surveys, measuring equipment owned by the Faculty of Civil Engineering in Skopje was used, while the surveys were done by an operational team from the public enterprise managing the reservoir.

The used measuring system consists of two parts: spatial geographic positioning system (GPS) and ultrasonic bathymeter (exo sonder) that functions at a frequency of 200 kHz. This system generates measuring points on the bottom of the reservoir in absolute x, y and z coordinates. The usual accuracy is 0.1 m along z-axis, i.e., along depth and several centimeters in horizontal plane (x and y coordinates).

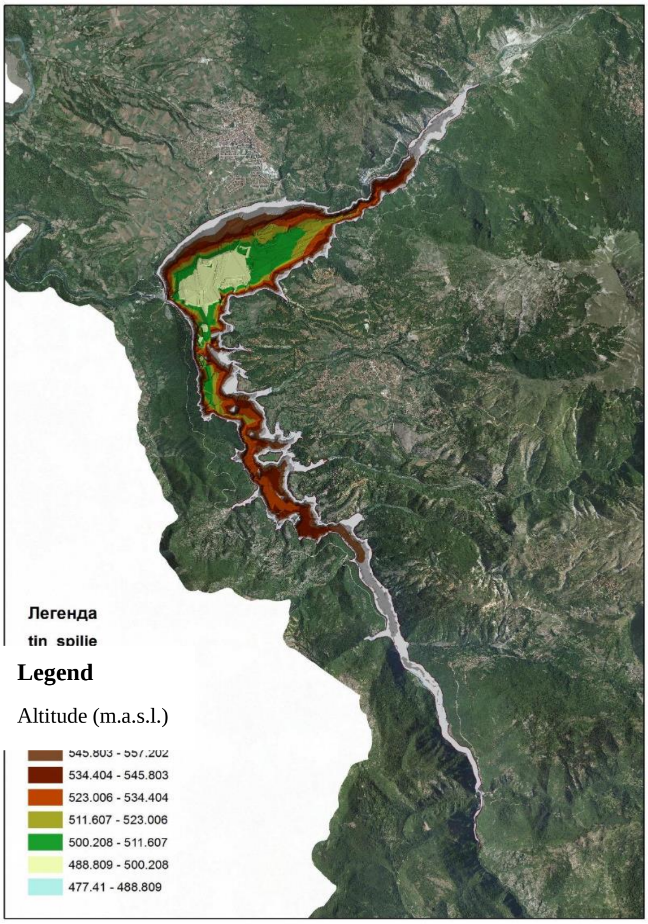

Fig. 2 Digital terrain model (DTM) of the Shpilje reservoir bottom

Based on the recorded water depths and known water level of the reservoir in the period when the measurements were performed, the absolute levels of the reservoir bottom were computed. These data were used to generate a digital terrain model (DTM) of the reservoir bottom (Figure 2).

3. Analysis of Results from Measurements

The surface areas of the water table were calculated using the previously generated DTM of the reservoir. For each water level, the surface area of the water table was computed starting from the lowest measured level of the terrain (492 m above the sea level) to the normal level (580 m above the sea level). The dependence of the water table surface area A(ha) on the water level Z (m above the sea level) is presented in Figure 3. For the purpose of comparison, the same figure also shows the initial distribution of the reservoir surface areas in the period when the structure was put into operation in 1969.

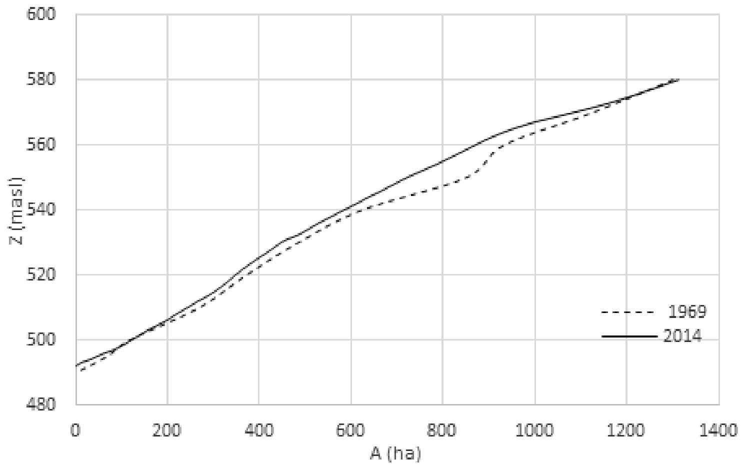

Fig. 3 Lines of Shpilje reservoir surface areas – initial conditions in 1969 and conditions in June 2014

The elementary volume, or the volume of the reservoir between any two adjacent water levels can be defined by integration of the surface below the curvature of surfaces, while the cumulatively summed up elementary volumes yield the volume curvature, $V = f(Z)$.

To compute the elementary volumes from the numerical data in this study, the method of smoothed contoured surfaces was used.

According to this method, the elementary volume is computed as follows:

$$DV = \frac{A_i + A_{i-1}}{2} \times (Z_i - Z_{i-1})$$

where:

DV – elementary volume between two successive surfaces of the water table (Ai и Ai-1)

Z – water level for the analyzed surfaces (m above the sea level)

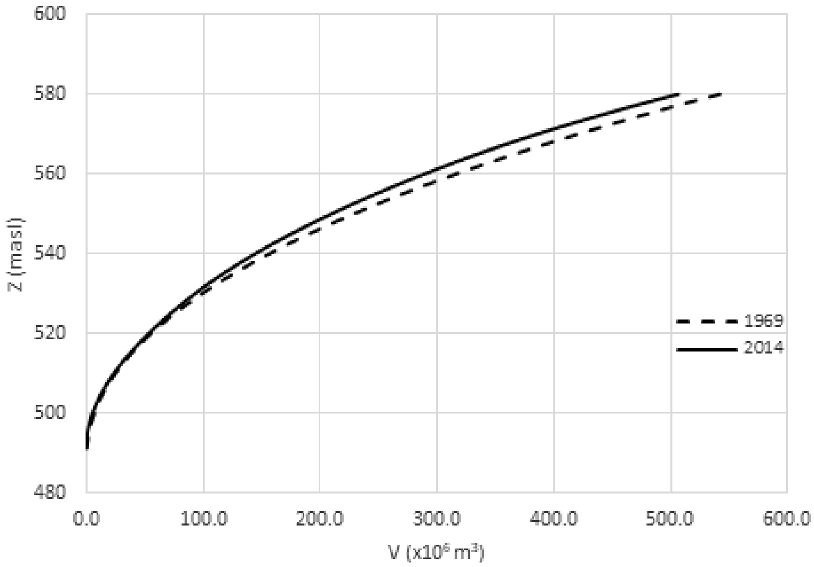

Fig. 4 Line of volumes of Shpilje reservoir – initial conditions in 1969 and conditions in 2014.

From the volumes line (Figure 4), the following data can be obtained:

In the case of a normal level of the reservoir Znl = 580.0 masl, the total volume of the reservoir amounts to:

$$Vnl = 506{,}32 \times 10^6\ m^3.$$

According to data available, the initial volume of the reservoir at normal level amounted to:

$$Viv = 543 \times 10^6\ m^3$$

In the period from the beginning of operation of the structure in 1969 until 2014 when the last measurements were done for the reservoir, a total of:

$$Vsed = 36.7 \times 10^6\ m^3 \text{ were deposited.}$$

To the minimal operational level of HPP Shpilje, Zmol = 562.5 masl, there corresponds a volume of:

$$Vmol = 311 \times 10^6\ m^3.$$

The present available storage capacity of the reservoir amounts to:

$$Vscp = Vnl - Vmol = 195.32 \times 10^6 m^3$$

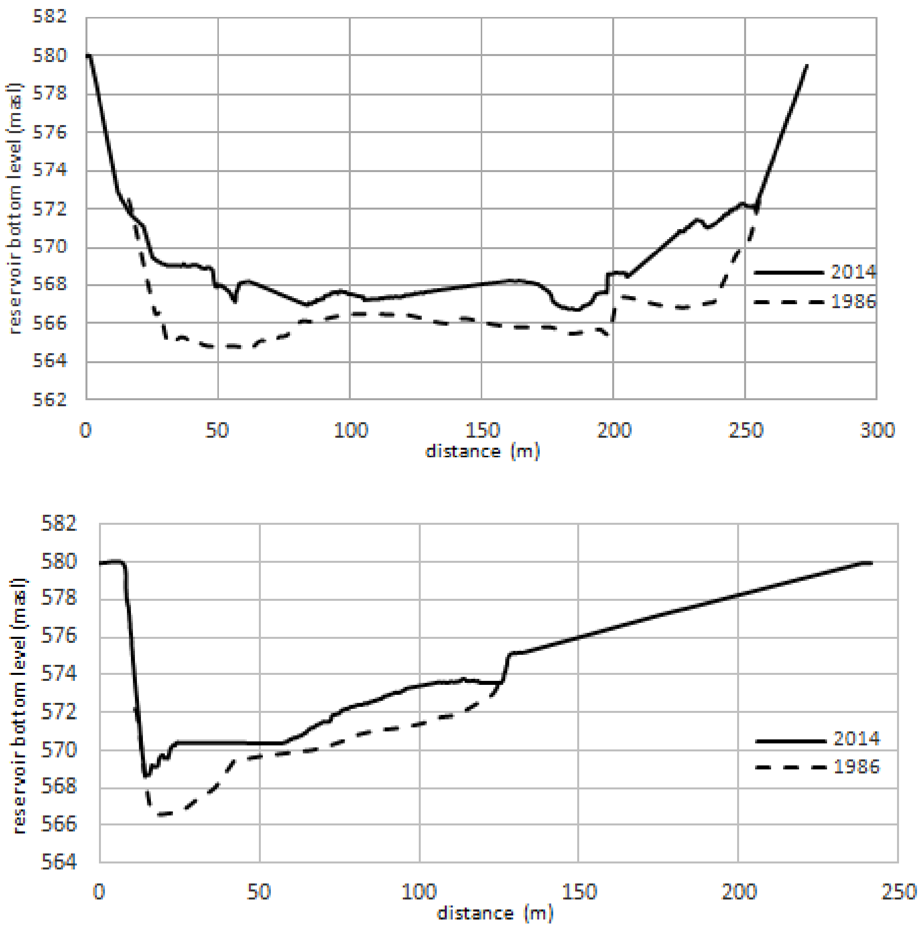

Fig. 5 Characteristic cross-sections along the Crn Drim and the Radika rivers

The analysis of distribution of sediments was done by comparison of the reservoir bottom configuration at selected cross-sections and longitudinal sections. The cross-sections of the reservoir were established upon previous survey of the bottom done in 1986. Longitudinal sections were also elaborated for the two arms of the reservoir, namely, along the Crn Drim River and the Radika River water courses, with presented conditions at the lowest points of the bottom recorded during the previous survey in 1986 and conditions recorded during the survey until 2014. This provides a clear high quality presentation of the distribution of sediments in the reservoir.

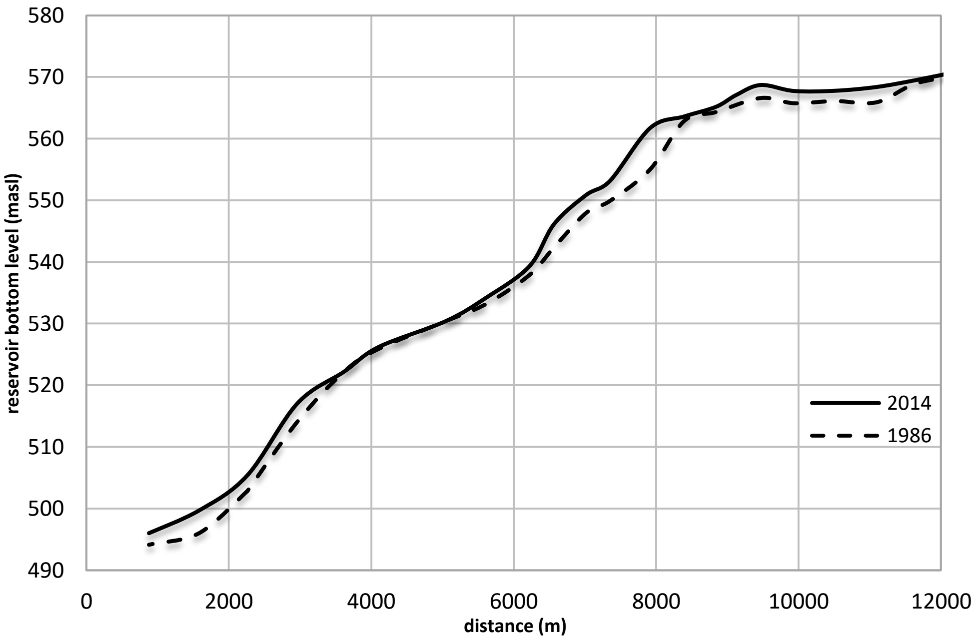

Fig. 6 Longitudinal section of the reservoir along the Crn Drim River water course

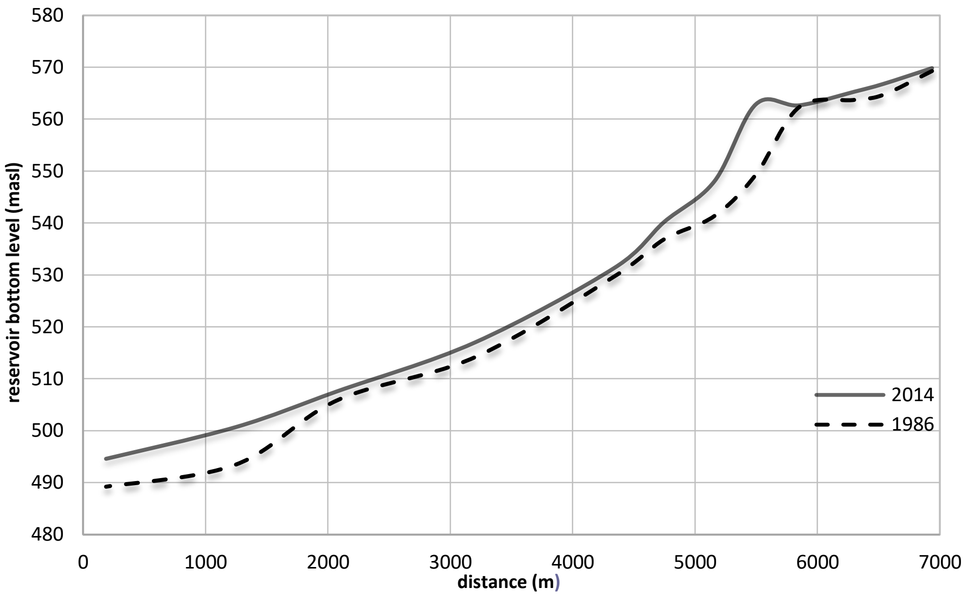

Fig. 7 Longitudinal section of the reservoir along the Radika River water course.

4. CONCLUSIONS

Based on the survey of the Shpilje reservoir bottom in 2014 and the performed analyses of the sedimentation process, the following conclusions are drawn:

- The sedimentation process in the reservoir takes place along the entire length of the reservoir, both along the Crn Drim River and the Radika River;
- As to the Crn Drim River arm, the most intensive silting is observed in areas where side tributaries empty into Crn Drim on the left and the right side of the reservoir.
- Along the Radika River arm, the most intensive silting is observed in the area where the Radika River empties into the reservoir. The configuration of the bottom of the reservoir in this area is extraordinarily variable and susceptible to dynamic processes of erosion and silting;
- Regarding the silting intensity, there stands out the zone of the reservoir between level 540 and 570 m above the sea level which corresponds with positions where the stated tributaries empty into the reservoir;
- In addition to the effect of the immediate basintributaries, it should also be mentioned that there is an intensive bank erosion and local collapses of the reservoir banks.

To reduce the production of eroded material in the Shpilje reservoir basin and the transfer of that material to the reservoir, the following measures have been proposed:

- Elaboration and proposal of possible forest-reclamation works for the purpose of reduction, i.e., elimination of erosion processes in the basins of the reservoir tributaries characterized by extensive erosion processes;
- Detailed checking of the already constructed anti-erosion structures in the basin of the lake and proposal of adequate measures for repair, reconstruction and possible construction of new structures that will control the transfer of eroded material into the reservoir;
- Construction of a sedimentation tank along the Radika River course, immediately upstream from the place where it empties into the lake. With this structure, the transfer of sediments to the reservoir will be controlled and certain income for the local community will be achieved by its regular cleaning and separation of the deposited material;
- Continuation of monitoring of the reservoir silting at each 5 to 10 years and after each big torrential downpours and taking corresponding anti-erosion measures accordingly.

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BATIMETRIJSKA MERENJA U AKUMULACIJI ŠPILJE

Periodična batimetriska merenja se izvode kako bi se definisala količina istaloženog materijala u akumulacijama, kao i određivanje najugroženijih područja usled procesa sedimentacije. Ovaj vid merenja u Republici Makedoniji započela su kao obavezna i redovna praksa sedamdesetih godina prošlog veka, neposredno nakon formiranja većih akumulacionih jezera. One su sprovodene na skoro svim akumulacijama u zemlji i može se reći da o nekima od njih već postoji dovoljno podataka koji mogu poslužiti kao osnova za kvalitetne analize trenda zapunjavanja jezera kao i stepena erozije u slivnom području. Ovaj rad pruža pregled rezultata najnovijih terenskih merenja i analiza promena u konfiguraciji dna akumulacije Špilje, sprovedene u periodu od 2014 do 2016. godine.

Ključne reči: *batimetriska snimanja, zapremina akumulacije, zapunjavanje sedimentima*