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SILTATION OF MODRAC HYDROACCUMULATION FROM ASPECT OF USABLE VOLUME

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SUMMARY

Modrac hydroaccumulation is the largest and most important multi-purpose water resource for water supply to large industrial capacities of importance for Bosnia and Herzegovina, but also for public water supply of Tuzla and Lukavac. Since the water quality of the hydroaccumulation is threatened by the waste water of a large number of different pollutants in the basin area of 1.189 km², and that the useful volume of hydroaccumulation is limited, then during the time it comes to the filling of the hydroaccumulation dominated by coal dust from coal mines in the basin reservoirs. It must be ensured that good quality water is supplied to consumers, especially households and industries, while ensuring hydrobiological minimum dilution of waste water discharged into the river Spreča downstream from dam and reservoir Lukavac.

Keywords: *hydroaccumulation, dam, sediment, useful volume*

INTRODUCTION

The idea of the possibility of building hydroaccumulation in the middle of the river Spreča with the dam in the strait Modrac directly downstream from the mouth of the Turija river, created in the early 50s of the twentieth century. The growing needs of Tuzla basin have initiated such a solution, a natural narrowing of the riverbed at the site near Modrac village provided a very suitable opportunity for its implementation. Several circumstances contributed to the delay in implementation of the procedure. The building has demanded large investments, which in conditions of low accumulation could not be provided. In addition, there is a dilemma about the sinking of a substantial part of the Sprečko field, which effectively meant reducing the already scarce agricultural land. The rapid growth of industry had a crucial impact on overcoming these problems and taking final decision on the realization of the investment.

During the construction of the dam, demands culminated for greater effectiveness of the hydroaccumulation, leading to modification of already finished main project and its orientation to raise the level of water in the corner of the 203 meters above sea level. The dam was built at the end of 1963, filling the reservoir was completed in February 1964, since when the hydroaccumulation and dam have been continuously operating [1].

The Hydroaccumulation has an extraordinary suitable position that in line combines natural and economic conditions. The natural advantage is deep cut of riverbed Spreča through the anticline Modrac, which closes syncline Sprečko field. Narrow profile in the form of straits, along with a suitable tectonics and favorable characteristics of sedimentary soil - durable serpentine massif, resolve the issue of the dam. Other natural advantage lies in a central position in relation to the location of the hydroaccumulation to the area of the basin. The site divides the Spreča river valley to the upper and lower Sprečko field, which is important for controlling the horizon, the power and grip accumulation in the field of balancing the water regime in the basin. Due to the central location, the accumulation can controll 60% of the basin. The third natural advantage is the nearness to major industrial facilities, and major consumers of water. Also, a favorable moment of nature is corresponding decrease in the Sprečko valley. Upstream of the Modrac strait fall of the valley ranges from 1% to 1.4%, and this circumstance allows the accumulation of large volumes of water with a relatively small dam [2].

Currently the system only meets the water supply of industry and part of the water suply of population with drinking water and reduces large water waves. It also ensures the production of electricity, to a smaller extent.

Elements of the area and volume of hydroaccumulation determine the third basic indicator of size and storage capacity, and it is installed flow. In the corner of the normal operating level, of 200 meters above sea level, capacity of water supply to consumers from the hydroaccumulation is 7 m^3/s, 2,3 m^3/s for the industry and 4,7 m^3/s for the dilution of waste water downstream from dams and hydroaccumulations.

In the corner of the projected maximum gradient, of 203 meters above sea level, capacity in the summer months is projected at 14 m^3/s, 7 m^3/s for the industry and 7 m^3/s for the dilution of waste water [3].

MORPHOLOGICAL CHARACTERISTICS OF MODRAC HYDROACCUMULATION

20 cross sections have been defines for monitoring purposes of the hydroaccumulation. It was indicated by permanent markings (concrete stones, plastic labels, bolts). The measurements are performed at regular intervals, in 1964, 1979, 1985 and 2002, with appropriate geodetic methods at the time, when were changes in the volume of accumulation, usable volume of accumulation, volume of introduced sediment and morphometric characteristics of the bottom monitored. Baseline data was established before the sinking area, i.e. in 1957. Each subsequent measurement gave the most credible display of reservoirs Modrac by advances in technology and methods of work [4].

The latest measurements were carried out in 2012, in which for the first time, thanks to advances in measurement technology, combined satellite, aerial photogrammetry and hydrographic measurement method. Hydroaccumulation is measured using two frequency bathymetry, to display three-dimensional view layers of sediment on the bottom of the lake. By integrating these measuring methods of terrain and hydroaccumulation, in 424 transverse profiles, of which 404 new and 20 old profiles, and 6 longitudinal sections, the volume of water and sediment, the actual configuration of the coast, three-dimensional models of depth, sediment and coastal areas, as well as other relevant the morphometric characteristics of the hydroaccumulation are defined, as shown in the table 1.

Table 1. Morphological characteristics of Modrac hydroaccumulation

Characteristics	1964.	1985.	2012.
Area (km^2)	17,1	16,75	16,69
Total volume (m^3)	98×10^6	88×10^6	102.759. 629,92
Usable volume (m^3)	77×10^6	76×10^6	87.739.727,16
Maximum depth (m)	18,0 (10,0)	18,0 (10,0)	14,94 m (bottom level)
Average depth (m)	5,7	5,2	5,32
Maximum length (m)	10.700	10.400	10.475,72
Maximum width (m)	1.600	1.780	2.411,17
Length of coast (m)	33.250	31.700	42.537,63

CATCHMENT AREA CHARACTERISTICS OF MODRAC HYDROACCUMULATION

The total catchment area of the Modrac hydroaccumulation is 1.189 km². Catchment of Modrac hydroaccumulation includes municipalities Banovici, Zivinice, Kalesija, and partly Kladanj, Tuzla and Lukavac, in Tuzla Canton, and municipalities Osmaci and Šekovići in the Republic of Srpska.

The main tributaries of Modrac hydroaccumulation are the Spreča river, with a catchment area of 832 km² and the Turija river with catchment area of 240 km² and also smaller streams in the immediate catchment of accumulation, and this Suha, Maoča, Prilučka river, Ugar, and Mednica, with a total catchment area of 117 km². The total length of watercourses in the basin of the reservoir is 521,3 kilometers, Figure 1.

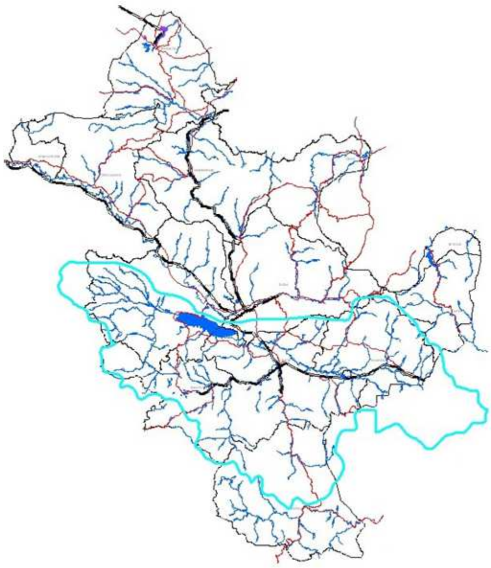

Figure 1. Hydrographic network catchment of Modrac hydroaccumulation

Significant right tributaries of the Spreča river, observed downstream, are the water flows Ljeskovica, Crna Bara, Bukovica, Dubnica with Kalesijica, Međaš, Gribaja, Krivača, Lješnica and Brestovik. Left tributaries of the Spreča river are Paprača, Mramorak, Mala Spreča with the Gračanica river, Krivača and Oskova. The main tributaries of the Oskova river are Litva and Gostelja with Zatoča, Suha, and Tarevčica. The tributaries of the Turija river are Duboki potok, Seona, Orahovica, Brijesnica and Bukovica.

Hydrographic network of torrential streams in the basin is highly developed, with a large number of watercourses. Torrent streams entries erosion deposits to Spreča and Turija, which through them reach the hydroaccumulation [4].

From geomorphological aspects basin of Modrac hydroaccumulation is characterized by advanced forms of relief, but without the extreme elements. Central tilt of basin is 22,9%.

It is very important, from the point of erosion processes, that there is a good erosion protection on the greater part of the basin. Forests covers about 50% of the total basin, pastures about 10% of the catchment area, and arable land about 40% of the catchment areas. The presence of "bare" land in the basin is almost negligible.

WATER QUALITY OF WATERCOURSES IN CATCHMENT

Based on multiple studies of water quality of watercourses in the catchment of Modrac hydroaccumulation, it was found that the surface waters are excessive polluted and that the quality of water, in the previous period and today, is far worse than the level defined by the applicable regulations on the categorization and classification of waters in Bosnia and Herzegovina.

This situation is the result of daily discharge of untreated municipal and industrial waste water into watercourses in the basin of Modrac hydroaccumulation. The greatest negative impact on the quality of water in the hydroaccumulation has the intake of suspended materials, as a result of mining activities in the basin and also nutrients substances that are the result of discharges of urban waste water in urban centers in the basin. In addition, there is a significant number of uncontrolled diffuse pollutants, such as rural areas, that do not have sewage systems.

According to applicable legislation of Bosnia and Herzegovina, the *Regulation on categorization of water courses* and the *Regulation on classification of waters*, in the area of the basin of Modrac hydroaccumulation all watercourses are classified in category II watercourse or class II water quality [5].

According to the results of so far conducted tests of water quality, it can generally be said that almost all the streams in the catchment area of Modrac hydroaccumulation are in poor condition compared to the prescribed classes. Critical streams based on pollution are:

- The Litva river, upon receipt of waste water " Separations "
- The Oskova river, after the confluence of Litva,
- The Gostelja river, after receiving wastewater from the coal mine "Đurđevik" (caves and separations)
- The Oskova river, after confluence of Gostelja river,
- The Spreča river, after confluence of the Oskova river to Modrac accumulation

Extremely poor water quality of these rivers is due to the high content of suspended matter, then the content of organic and other pollutants that discharged into surface water by the waste water. Pollutants from municipal waste water, mainly contain organic substances which is relatively easily degradable. The bigger problem is that these pollutants in waste water contain increasing concentrations of nitrogen and phosphorus compounds that have an impact on surface waters, in this case primarily on the water of Modrac hydroaccumulation, which favors the process of eutrophication of water in this hydroaccumulation [4].

According to the research of watercourses conducted in 2010, Table 2 presents the results which indicate a very high content of suspended matter in the water of "critical" watercourses Litva, Oskova, Gostelja and Spreča.

Table 2. Content of suspended matter in watercourses of Modrac hydroaccumulation basin for 2010 (mg/l)

Watercourse	Profile	MAC Class II water	Established value
Spreča	Osmaci, above Kalesija	30,0	2,1
Spreča	Before the confluence of Gostelja river	30,0	9,0
Spreča	After the confluence of Gostelja river	30,0	292,9
Litva	Before Separation Banovići	30,0	34,9
Litva	After Sparation Banovići	30,0	1.560,9
Oskova	Mačkovac settlement	30,0	1,4
Oskova	After confluence of Litva river	30,0	1.389,0
Gostelja	Before coal mine "Đurđevik"	30,0	0,5
Gostelja	After coal mine "Đurđevik"	30,0	50,4

DECREASE IN VOLUME OF MODRAC HYDROACCUMULATION

According to the conducted geodetic and hydrographic measurements in 2012, the total amount of sediment entered in Modrac hydroaccumulation, from its formation, amounts to 15.025.121 m³, and the total, and most of the useful volume is reduced for the same value. One part of the silt, the greater granulation, has a higher possibility of settling and it was deposited in the area of Spreča confluence, on the surface of 4-5 km² or in space of more than 25% of the total volume of reservoirs, and also in the area of Turija confluence, Figure 2. Height deposited coatings ranges from 0,5 to 2,5 m [4,6].

Figure 2. Zones of sediment accumulation in Modrac reservoir

Excessive intake of suspended materials, which are deposited, contribute to reducing the depth of water in the accumulation by supporting faster development process of eutrophication. Too much of sedimented suspended matter allows the accumulation of organic and nutrient matters in the sludge, which also favors the faster development of the eutrophication process.

In Modrac hydroaccumulation next to natural process of sediment accumulation, there is anthropogenic factor in relation to mining activities in the wider area of the basin. Spreča riverbed, before the entrance to the Modrac accumulation, is characterized by a large number of sandbars. The sandbars are formed by stopping of the deposits, which comes from the river basin.

The deposit, which comes from the area of the mine as a loss on mining facilities, has fine granulometric structure and is transported in the form of suspended sediment, so it does not participate in the forming of sandbars in the Spreča riverbed. That means that one part of the deposit, which comes from the river basin, does not reach the reservoir and do not participate in its siltation. However, bearing in mind that the pulled deposit represents only about 10% of the total sediment transport, forming sandbars does not significantly affect the overall balance of sediment in the accumulation.

On the other hand, sandbars reduces throughput capacity of thr riverbed contributes to an increased discharge of high water. Spreča riverbed is not large enough to accommodate the large water. The presence of a secondary water occurs pouring from the riverbed, and a coarse hydraulic analysis shows that at flow rates from 35 to 40 m³/s causing outpouring outside the main channel [7].

The problem of flooding significantly occurs upstream of the accumulation. Flood zones are located immediately upstream of the line of expropriation that is set along the contour line on 200 meters above sea level for the state before the forming of accumulation.

In the process of covering with sediment of accumulation, its volume is reduced, and consequently the retention capacity also. This means that, at the same inlet and outlet of water from the accumulation, have to raise the water level, because the transformation of flood waves depends on the storage capacity. Analysis of the impact of accumulation's volume to transform flood waves was carried out for several observed flood waves, in the prescribed evacuation mode elements on the dam.

The paper considers the case of 13-day hydrograph flood that took place from May, 28th 2010 to June, 9th 2010, Figure 3. It is assumed that the water level in the accumulation was at minimum operating level (Z = 195,00 meters above sea level). It was determined that the maximum emphasis on the fundamental discharges (Q_{max} = 77 m³/s) begins when the water level in the accumulation was above 196,50 meters above sea level.

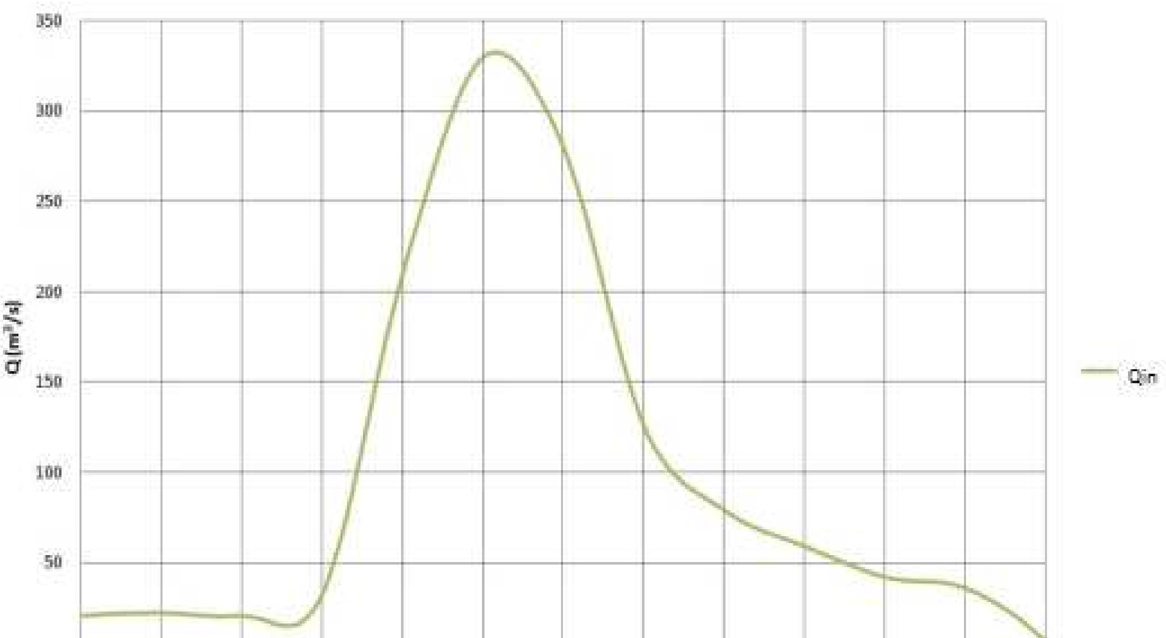

Figure 3. The flood waves hydrograph for the period May, 28th 2010 to June, 9th 2010

It is the security level to which water level drops in the accumulation during high waters period, as defined by accumulation's management plan from July, 3rd 2014. The reservoir is poured out through the bottom outlet until it reaches the normal level, Z_{nl}= 200 meters above sea level, after which the evacuation of the water is performed by overflow too.

The impact of siltation of Modrac accumulation can be seen in Figure 4. For the conditions of the accumulation from 1957, the maximum level that could be achieved under such conditions would be $Z_{max\ (1957)}$ = 200,15 m above sea level, while in conditions of 2012, maximum level was $Z_{max(2012)}$ = 200,32 m above sea level, which is the camber level in accumulation of 17 cm.

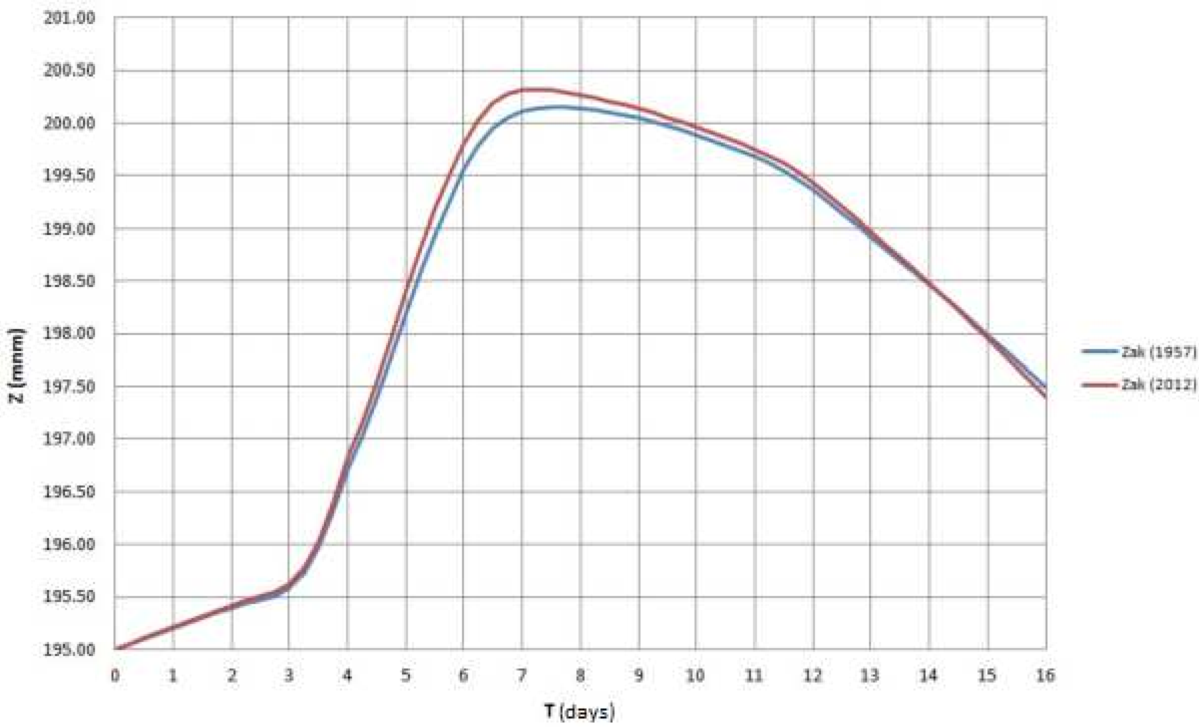

Figure 4. The level of the water in the accumulation in 1957 and 2012
the initial level of 195 m above sea level

Based on the hydrograph from Figure 4, it can be concluded that the reduction in volume of Modrac accumulation, due to siltation, has very little effect on the increase of water level in the waves of high water (ranging from 10 to 20 cm). This increase of water level also causes an increase in flood areas, but this effect is virtually negligible.

METHODS FOR ELIMINATION OF DEPOSITS

It is necessary to define the management strategy for sediment with the realization of these following steps [8,9]:

a) Removing seven million m³ of sediment from the delta of the Spreča river and the Turija river, by a combination of dry excavation and hydraulic dredging, Figure 5.

b) After removing the sediment, to form a lagoon separated by dikes from the main body of accumulation. Lagoon will "intercept" sediment transport and thus prevent its entry into the Modrac accumulation, FIgure 6.

c) Use a sedimet material for reclamation of exploited mine caves or, more economically feasible, to create a new multi-purpose plateau between planned lagoons and reservoirs for agriculture, tourism or other development needs Figure 7.

Figure 5. Laguna for interception of sediment in Modrac accumulation

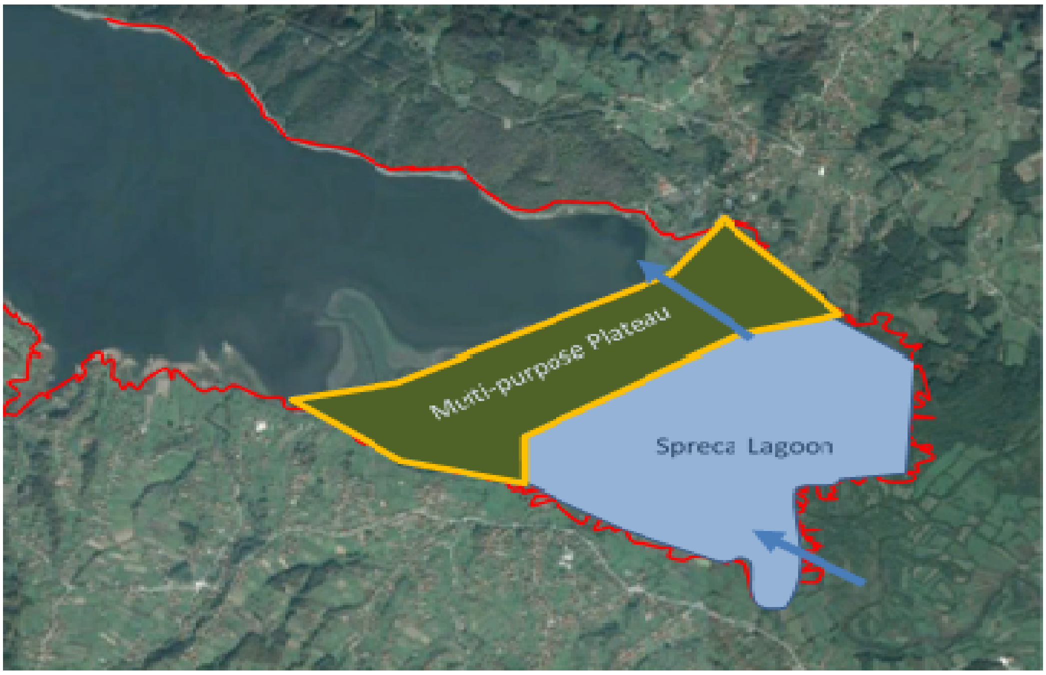

Figure 6. Multipurpose plateau between the lagoon and accumulation – concept of solutions

Figure 7. Multipurpose plateau between the lagoon and accumulation for recreational purposes

Other necessary procedures to protect Modrac accumulation, in terms of reducing the amount of introducing sediment, are related to the removal of "wild" waste landfill close to the Spreča and theTurija riverbeds, and also stabilization of river banks in the area where they are vulnerable to erosion. It's necessary to build regulation of the Spreča river and the Turija river and construction of dykes to defend against flood.

CONCLUSIONS

Based on the analysis, it can be concluded that there is a dominant zone of silting that is located on the east side of the accumulation, the area of Spreča river delta. There are separations, mine caves and surface mines in the Spreča river basin. This siltation zone of accumulation is the most important for the considered problem of reducing the usable volume and possibility of delivery of water to users, then the maintenance of water management minimum downstream from the dam and reception and mitigate floods. In addition, this zone is relevant for the understanding of the effects on the occurrence of flooding in the zone of the Spreča river.

Changes due to the siltation, which are registered in the eastern zone of reservoirs are of such intensity that is sufficiently confident to make a quantification of the deposited coating. This means that it is completely justified that the silting zone is analysed in details.

Siltation of the hydroaccumulation in the eastern zone, from level 193 m above sea level or upward, in the initial state, has a dominant effect on the reduction of the useful volume that is defined as level between 195 m and 199-200 m above sea level.

It can be concluded that the siltration, which is registered in the period up to the measuring of 1985, was intense and included the upstream part of accumulation near the delta of the Spreča river. This deposition had the biggest negative impact on the accumulation since the deposits formed in the space of useful volume. Then, in the later period of time, the deposition is moved towards the central zone of hydroaccumulation taking small part of the useful volume and the space below the usable volume, or the so-called „dead volume".

If siltation value of 15.000.000 m^3, is taken as representative of 48 years of the Modrac accumulation existing, obtained that registered intensity of siltation amounted to about 260-270 m^3/km^2.year. From these values around 150 m^3/km^2.year. can be assessed as a natural entry, while the remainder of about 110 to 120 m^3/km^2.year was a result of anthropogenic influences. In percentage terms, provided the following applies:

- total filling: natural entry: anthropogenic influence in the ratio 1: 0,6: 0,4.

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REFERENCES

[1] PC for water management activities "Spreča". Data of Modrac accumulation depending on level in the accumulation, 2012.
[2] Report on the state of Modrac accumulation and needs for continuous monitoring, PC "Spreča" Tuzla, 2012th.
[3] PC for water management activities "Spreča". The operation plan of the dam Modrac, 2005.
[4] Institute for Water Management "Jaroslav Černi" Belgrade. Siltation of accumulation, flooding and management, Annex 1, 2013.
[5] Suljic, N. (2014). Fundamentals of mechanics-the theory and tasks. Tuzla. University of Tuzla.
[6] The Coordination Team for the protection of Modrac accumulation. The impact of wastewater from the mine coal to accumulation Modrac, 2013.
[7] Energoinvest, Sector - Higra, Sarajevo. Rules on maintenance, use and observation facilities and equipment of multi-purpose water management system, 2007.
[8] Holinger IR International Consultants. Feasibility study - summary of the project, Tuzla – Modrac lake, 2016.

[9] Suljic, N., Hodžić, D. (2016). The analysis of water release from the hydro accumulation lake Modrac with spillway curve and volume curves. Bijeljina, Archives for Technical Sciences, Year VIII, No.14, pp. 29-34.