ANALYSIS OF RUNOFF COEFFICIENT FOR CATCHMENT AREA OF MULTI-PURPOSE "MODRAC"

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Summary: *The major task of multi-purpose reservoir „Modrac" operation is to decide how much water should be released now and how much should be retained for future use given some available and/or forecasted information at the beginning of the current time period. In practice, reservoir operators usually follow rule curves, which stipulate the actions that should be taken conditioned on the current state of the system. Through construction of the dam Modrac in 1964, the reservoir of the same name was formed. It's primary objectives were the provision of technological water for industries in the Tuzla region and mitigation of downstream floods as well as recreation and other purposes. This paper presents an analysis of runoff coefficient in correlation of annual precipitation and mean annual inflows for the catchment area of the multi-purpose reservoir „Modrac" for the period 1999 - 2018.*

Keywords*: multi-purpose reservoir „Modrac", runoff coefficient, precipitation, inflow, catchment area*

1. INTRODUCTION

The current way of producing energy is the main "culprit" for human activity caused by climate change, while the water regime, with all its consequences, the first major "victim". High waters are increasing and occurring more and more often, while low water and drought reduced last longer [1].
Multi-purpose reservoir "Modrac" is formed in 1964 with the construction of a dam in the gorge Modrac. It is formed by the rivers Spreča and Turija with its river tributaries. The total catchment area in the profile of the dam is approximately 1189 km^2, which accounts for over 60% of the entire river basin to prevent this. Of the total area of the basin, river

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Spreča occupies 832 km^2, river Turija occupies 240 km^2, while the rest of the basin belongs to the immediate basin reservoirs 117 km^2 [2].

For the dimension of normal backflow 200.00 (m.a.s.l.) reservoir provides, on average, 2,30 m^3/sec of raw water and 4,70 m^3/sec as hydro biological minimum for the river Spreča, looking downstream from the dam (projected state) [2].

Multi-purpose reservoir “Modrac” solves several hydrologic and extremely economic aspects as supply of population, industry and thermal capacity of Tuzla and Lukavac with technological water, dilution of wastewater discharges Tuzla and Kladanj industry, the increase of flow of Spreča river downstream of the reservoir during the summer, electricity production in a small hydropower, mitigates high water flood flows with retention influence of reservoir and prevent or significantly reduce flooding in the river valley Spreča downstream of the reservoir.

However, the actual amount of water in the reservoir may vary over the short term depending on rainfall and other conditions [3].

Flood control dams store all or a portion of the flood waters in the reservoir, particularly during peak floods, and then release the water slowly [4].

According to the Law on the Protection of accumulation "Modrac" uses of reservoir “Modrac”, in order of priority, are [2]:

- the provision of water for the population,
- the provision of water for industry,
- protection from flooding downstream of the dam,
- the provision of hydro biological minimum for river Spreča, downstream of the reservoir,
- development of tourism, recreation and water sports, in accordance with the Law,
- the production of electricity on small hydroelectric using excess water in the profile Modrac.

According to the latest geodetic and hydrographic measurements reservoir "Modrac" has the following morphometric characteristics [5]:

- total area of the reservoir “Modrac” is 16,69 km^2,
- total volume of water in reservoir “Modrac” is 102.759.629,92 m^3,
- useful volume of water in reservoir “Modrac” is 66.522.627,23 m^3,
- maximum depth of the reservoir Modrac is 14.94 m (bed elevation),
- the average depth of the reservoir “Modrac” is 5.32 m,
- maximum width of the reservoir “Modrac” is 2.411,17 m,

The Modrac dam is multi-armored reinforced concrete with 11 counterframes, with the following basic characteristics, Figure 1:

- construction height of dam H = 33.35 m;
- dam length in crown L = 205,0 m;
- level of the upper edge of the structure of the dam 205,00 m.a.s.l.;
- designed level of maximum downfall 203,00 m.a.s.l.;
- level overflow fields of the dam - angle of normal slowdown 200,00 m.a.s.l.;
- minimum operating level: 194,00 m.a.s.l.;
- the four bottom outlets (number: 2, 6, 7 and 8). The maximum capacity (maximum shutter openness) of the basic drains is about 80.00 m^3/s [6].

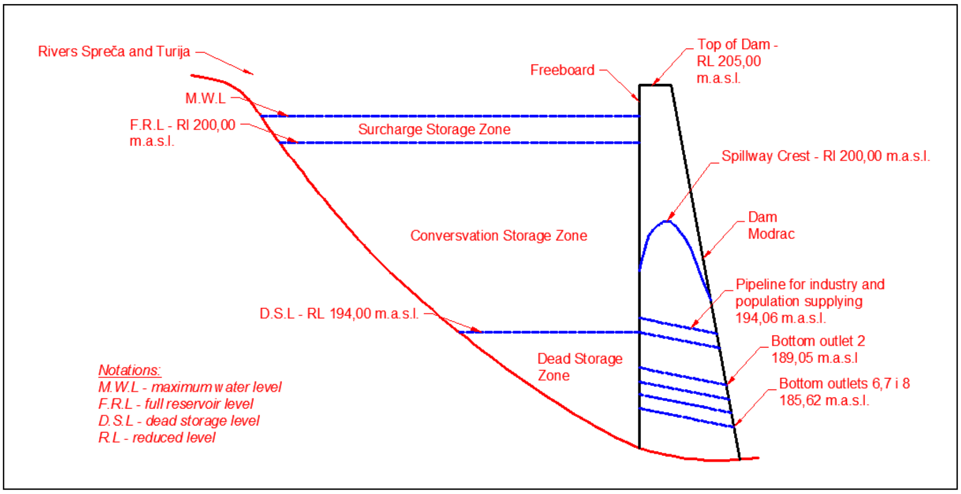

Figure 1. Charateristics of dam Modrac

The emergence of high water is extreme hydrological phenomena defined by an unusually high water level, flow or volume of water at a certain place at a certain time period. Causes and consequences of flooding is usually not be predicted, but can be mitigated. The consequences of floods vulnerability of human lives and material goods, huge damage, involvement of a large number of people and resources in the field, social insecurity of the population, etc [5].
Figure 2 shows digital orthophoto image of multi-purpose reservoir „Modrac“ where are visible enormous amounts of sediments at the coastline of lake Modrac [6].

Figure 2. Digital orthophoto image of multi-purpose reservoir "Modrac"

Due to climate change in the period from the formation of the multi-purpose reservoir „Modrac“ to the present day all major flood waves have been recorded. In Table 1 of 1965, April 1985, July 1986, May 1987, June 2001, March 2006, May/June 2010 and May 2014 [6].

Table 1. Review of the characteristics of registered flood waves [9]

Time to appear of flood wave	Maximum level H	Inflow Q_{inf}	Outflow Q_{out}	Retention of reservoir	Rainfall
	(m.a.s.l.)	(m^3/s)	(m^3/s)	%	(mm)
14.4. – 24.4. 1985.	201,09	406,50	201,10	50,53	81,16
15. 25.7. 1986.	200,74	272,10	154,90	43,07	117,57
3.5- 13.5 1987.	201,60	730,00	331,45	54,60	112,30
17.6. – 27.6. 2001.	202,12	619,10	466,36	24,56	60,20
29.5. – 8.6. 2010.	201,18	411,11	252,54	38,57	92,60
14. – 23.5. 2014.	203,42	1602,00	1137,00	29,00	213,90

The hydrographs of flood waves are determined on the basis of the natural flow into the reservoir. The hydrograph of outflows is determined by the discharge through the discharge facilitiess on the dam Modrac [9].
The discharge volume is controlled over the flow curve at the Modrac downstream station. The amount of discharges is regulated by the bottom outlets and spillway facilities and depends on the level of water in the reservoir. Since the amount of discharge is limited by the appearance of large flood waves, there is a rise in the water level in the reservoir (accumulation charge), and thus absorbs part of the volume of the flood wave, ie it makes the reduction of the maximum flow. The reduction of maximum flow downstream ranges from 16 to 55% depending on the size of the water wave and the state of the reservoir Modrac level [8].

2. PRECIPITATION CHANGES

In addition, to determine the trend of changes in precipitation for a sequence of years from 1999. to 2018., the following figure shows the maximum annual precipitation values. From the Table 2 it is visible that maximum value of precipitation (1434 l/m^2) has occured in 2014. All precipitation datas are measured climatological station „Modrac“ (K.S. Modrac) which is located at dam Modrac.
In the following table are shown values of mean annual precipitation for the catchment area of the multi-purpose reservoir „Modrac“ for the period 1999 - 2018.

Table 2. Mean annual of rainfall for the catchment area of the multi-purpose reservoir „Modrac“ for the period 1999 - 2018

Year	P_{sum} (mm)
1999	903.00
2000	403.40
2001	1021.00
2002	746.30
2003	781.10
2004	1037.80
2005	1133.20

2006	1022.52
2007	928.81
2008	803.20
2009	850.60
2010	1258.10
2011	530.50
2012	709.47
2013	850.50
2014	1392.33
2015	687.10
2016	989.20
2017	843.85
2018	966.50

3. INFLOW INTO MULTI-PURPOSE RESERVOIR "MODRAC"

On the profile dam Modrac there is no possibility of direct measurement of the natural inflow, but that it is determined from the dependence of volume changes and the amount of emphasis through outlets and spillway, using the water balance equation. This calculation is extremely reliable because it accurately measured using data on changes in the level and quantity of releases.
Inflow and outflow hydrograph calculation is based on the following equations:

1. Water balance equation: R= P – ET – IG – ΔS (1)
   where: P – rainfall
   R – runoff
   ET – evapotranspiration
   IG – deep/inactive groundwater
   ΔS – change in soil storage
2. Inflow and outflow equations with use of water balance equation:

$$\int_{t_0}^{t} Q_{inflow} dt = \int_{t_0}^{t} Q_{outflow} dt \pm \Delta V \qquad (2)$$

$$Q_{inflow} \cdot \Delta t = Q_{ouflow} \cdot \Delta t \pm \Delta V \qquad (3)$$

where:

$$Q_{inflow} \cdot \Delta t = V_{inflow}$$
$$Q_{outflow} \cdot \Delta t = V_{outflow}$$

Q_{inflow} – the amount of water that flows into reservoir,
$Q_{outflow}$ – amount of water that flows out of the reservoir,
ΔV – amount of water which remains in the reservoir

Typical display of mean annual inflow hydrograph for reservoir and dam are represented in Figure 4.

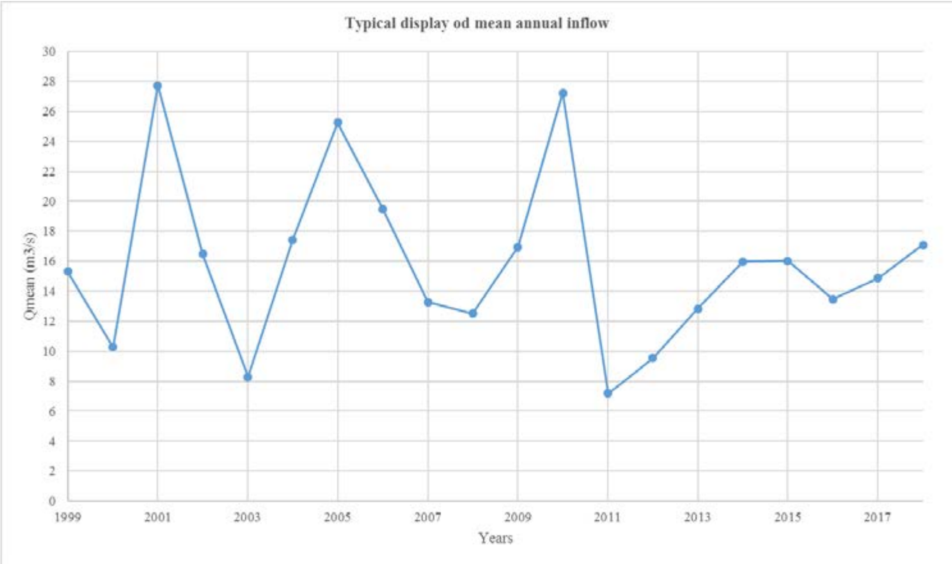

Figure 4. Typical display of mean annual inflow hydrograph for reservoir and dam

In the following table are shown calculated values of mean annual inflows for the catchment area of the multi-purpose reservoir „Modrac“ for the period 1999 - 2018.

Table 3. Mean annual inflows for the catchment area of the multi-purpose reservoir „Modrac“ for the period 1999 – 2018

Year	Q_{mean} (m^3/s)
1999	15.31
2000	10.26
2001	27.71
2002	16.48
2003	8.28
2004	17.43
2005	25.25
2006	19.46
2007	13.27
2008	12.53
2009	16.94
2010	27.23
2011	7.18
2012	9.53
2013	12.83
2014	15.98
2015	16.03

2016	13.48
2017	14.88
2018	17.10

4. RUNOFF COEFFICIENT OF MULTI-PURPOSE RESERVOIR "MODRAC" CATCHMENT

The average annual runoff coefficient η for the catchment area of multi-purpose reservoir "Modrac" was calculated on the basis of the data on measured annual rainfall amounts and the amount of water affixed to the multi-purpose reservoir on the basis of the balance equation, also at the annual level for the already contemplated period 1999-2018. years.

The average runoff coefficient η was obtained on the basis of the following form:

$$\eta = \frac{V_{outflow}}{V_{rainfall}} \qquad (4)$$

where:

$V_{outflow}$ – volume of outflow water (m^3)
$V_{rainfall}$ – volume of precipitation water (m^3)

Figure 5 shows average runoff coefficient for the catchment area of multi-purpose reservoir "Modrac" for the period from 1999-2018.

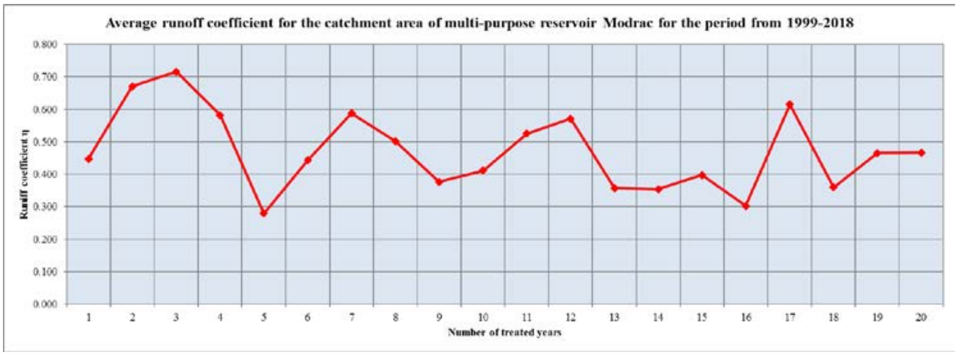

Figure 5. Average runoff coefficient for the catchment area of multi-purpose reservoir "Modrac" for the period from 1999-2018.

In the continuation of the article, it was presented the functional dependence between the runoff coefficient and the calculated annual flow (Q_{mean}) into the multi-purpose reservoir (Figure 6) and the dependence of the runoff coefficient and annual sum of the precipitation of P_{sum} (Figure 7) was presented for the period 1999-2018.

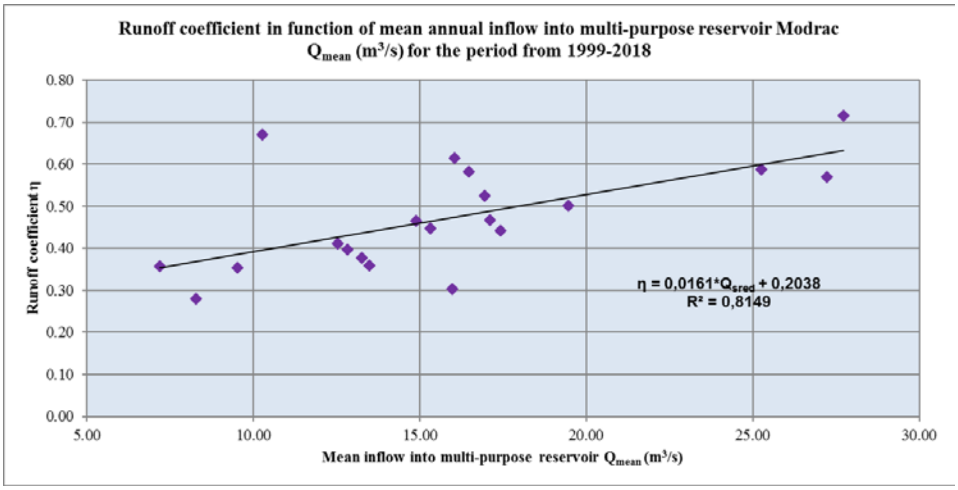

Figure 6. Runoff coefficient in function of mean annual inflow into multi-purpose reservoir "Modrac" for the period from 1999-2018.

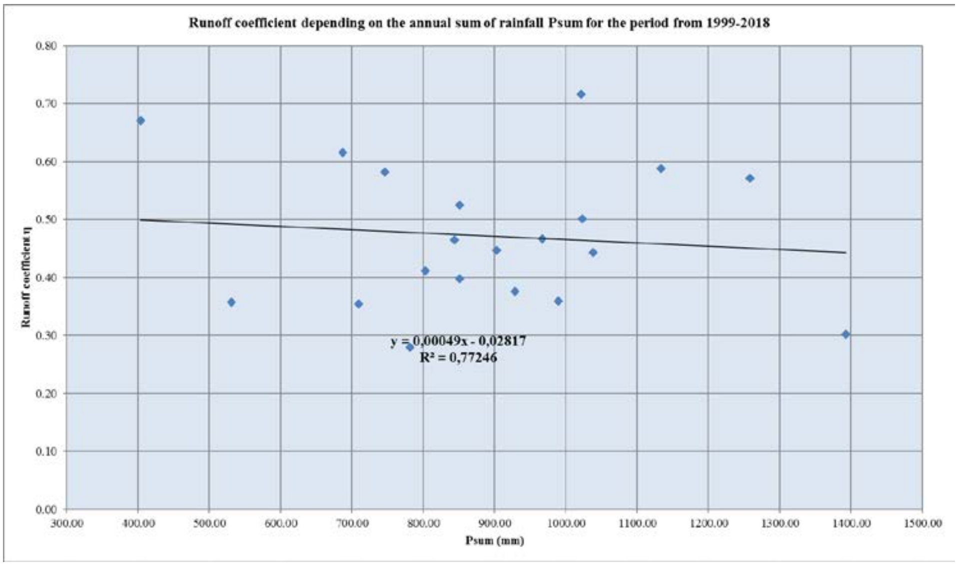

Figure 7. Runoff coefficient in function of annual rainfall into multi-purpose reservoir "Modrac" for the period from 1999-2018.

5. CONCLUSIONS

In this paper, the runoff coefficient η is presented in relation to the mean annual inflow into multi-purpose reservoir „Modrac" and the annual sum of precipitation on the catchment area of multi-purpose reservoir „Modrac". It is evident that the value of the coefficient of correlation R in relation to the runoff coefficient and Q_{mean} annual average inflow is R = 0.8149 which is a very positive bond (Figure 6), while in relation to the runoff coefficient and annual sum of rainfall the coefficient of correlation is R = 0.77246 which represents a medium positive bond (Figure 7). Also, it should be noted that the value of the mean annual runoff coefficient for the catchment area of multi-purpose reservoir „Modrac“ for the considered period was the lowest in 2002 and the highest in 2004 (Figure 5.).

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АНАЛИЗА КОЕФИЦИЈЕНТА ОТИЦАЊА ЗА СЛИВНО ПОДРУЧЈЕ ВИШЕНАМЈЕНСКЕ ХИДРОАКУМУЛАЦИЈЕ „МОДРАЦ“

Резиме: *Осноцни задатак хидроакумулације „Модрац“ представља колико воде треба бити испуштено и задржано за будућу употребу са заданим и/или прогнозним информацијама на почетку разматраног периода. У пракси, управљање хидроакумулацијама обично следује криве управљања, којима се утврђује која акција ће се подузети условљена тренутним станјем система. Са изградњом бране Модрац, која је изграђена 1964. године, формирана је и хидроакумулација „Модрац“. Основни циљеви хидроакумулације „Модрац“ јесте осигуранје технолошке воде за потребе индустрије у Тузланској регији, заштита поплава низводно од бране Модрац, као и осигуранје воде за потребе становништва града Тузле. Овај рад представља анализу коефицијента отицања у корелацији са годишнјим падавинама и среднјим годишнјим протицајима у хидроакумулацију „Модрац“ за разматрани пердиод од 1999-2018.*

Кључне речи: *вишенамјенска хидроакумулација „Модрац“, коефицијент отицања, падавине, доток, сливно подручје*