

ANALYSES OF THE INFLOW AND RUNOFF FOR THE CATCHMENT AREA USING THE EXAMPLE OF THE MODRAC RESERVOIR

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Summary

The main task of the multi-purpose reservoir "Modrac" is to regulate the water regime in a given basin while making decisions on the amount of water released, as well as the amount of water that needs to be retained for future use. Decisions are made on the basis of available data and forecast data. Since no forecast model has been developed, the operator of these complex processes must rely on forecasts that are more or less precise. In practice, dam and reservoir operators, in most cases, usually follow the rules of the curves (volume, flow, etc.), which determine the actions to be taken depending on the current state of the system. With the construction of the Modrac dam in 1964, the reservoir of the same name was formed. The primary goals were to provide technical water for industry in the Tuzla region and mitigate downstream floods, as well as recreation and other purposes. The paper presents an analysis of the runoff coefficient in the correlation of annual precipitation and mean annual inflows for the catchment area of the multipurpose reservoir "Modrac" for the period 1999 - 2024.

Keywords: multipurpose reservoir, runoff coefficient, precipitation, inflow, catchment area

1. INTRODUCTION

The current method of electricity production is the main cause, along with human activities, of climate change, while the water regime is the first to be hit, with all its consequences. Climatic changes are reflected in increasingly frequent changes in hydrological peaks, minimums (droughts) and maximums (floods). That is, high waters are increasing and occurring more frequently, while low waters and droughts last longer [1].

Hydroaccumulation "Modrac", as a multi-purpose reservoir, was created by the construction of the Modrac dam in 1964 in the Modrac strait on the Spreca River. The reservoir consists of the rivers Spreca and Turija with their tributaries. The total area of the catchment area in the profile of the dam is approximately 1189 km², which makes up over 60% of the entire Spreca river basin. Of the total area of the basin, the river Spreca occupies 832 km², the river Turija occupies 240 km², while the rest of the basin belongs to the accumulation of the immediate basin 117 km² [2].

The elevation of the normal operation of the reservoir is 200.00 m.a.s.l., the reservoir provides an average of 2.30 m³/sec of technical water and 4.70 m³/sec as a hydrobiological minimum for the Spreča River, looking downstream from the dam (designed state) [2].

The multi-purpose reservoir "Modrac" solves several hydrological and extremely economic aspects, such as supplying the population and industry, the cities of Tuzla and Lukavac with technical water, mitigating the flood wave downstream of the Modrac dam and reservoir, and producing electricity in a small hydroelectric power plant.

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

The dam serves for partial flood control, retaining the flood wave or part of the flood waters in the reservoir, especially during the peak flow, and then releasing the water through the base outlets according to the operator's established procedure [4].

Considering the latest geodetic and hydrographic measurements, the technical data of the reservoir "Modrac" are listed [5]:

- the area of the "Modrac" reservoir is 16.69 km²,
- the total volume of the "Modrac" reservoir is 102,759,629.92 m³,
- the useful volume of the "Modrac" reservoir is 66,522,627.23 m³,
- the maximum depth of the reservoir is 14.94 m,
- the mean value of the reservoir depth is 5.32 m,
- the maximum width of the "Modrac" reservoir is 2,411.17 m.

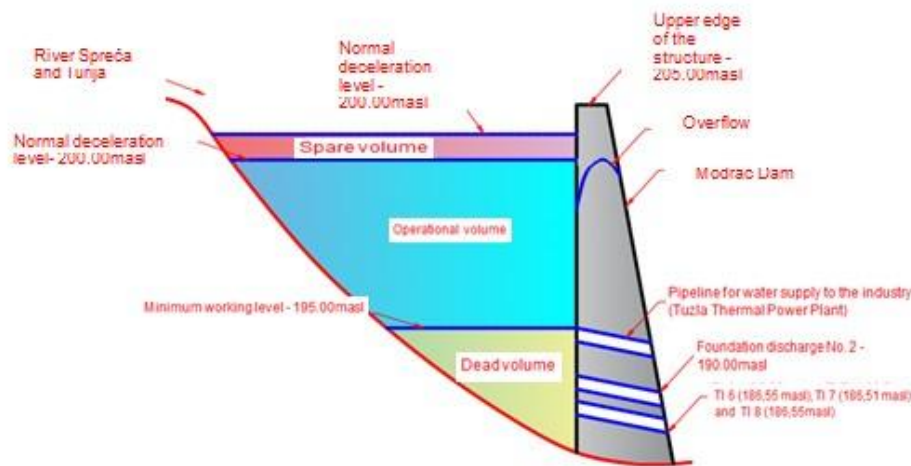


Figure 1. Characteristics of the "Modrac" dam

The "Modrac" dam is highly reinforced - a concrete arch dam with 11 buttresses, the technical characteristics of the dam are listed below, Figure 1:

- height of the structure $H = 33.35$ m;
- length of the dam crest $L = 205.0$ m;
- height of the upper edge of the dam is 205.00 m.a.s.l.;
- height of the spillway is 203.00 m.a.s.l.;
- working level of the dam is 200.00 m.a.s.l.;

- minimum working level is 194.00 m.a.s.l.;
- foundation spillways (number: 2, 6, 7 and 8). The maximum water discharge through the foundation spillways is 80.00 m³/s [6].

The phenomenon of high water is an extreme hydrological phenomenon defined by an unusually high water level, flow or volume of water in a certain place in a certain period of time. The maximum recorded water level of the "Modrac" reservoir was 203.42 m.a.s.l. due to prolonged rainfall in May 2014.

The causes and consequences of flooding are usually unpredictable, but they can be mitigated. The consequences of floods are the endangerment of human lives and material goods, huge material damages, involvement of a large number of people and resources on the ground, social insecurity of the population [5].

Also, as a result of soil erosion in the catchment area of the "Modrac" reservoir, there is an increased production of sediment, which reaches the reservoir, which results in its deposition in the reservoir and a decrease in its useful volume.

According to literature data, the reduction in the volume of the reservoir, even 10-20 years after their construction, amounts to 20 to 30% of the general volume of the reservoir [6].

In Figure 2, the digital model (DEM) shows the catchment area of reservoir with the hydrographic network of rivers and tributaries that gravitate to the reservoir [7].

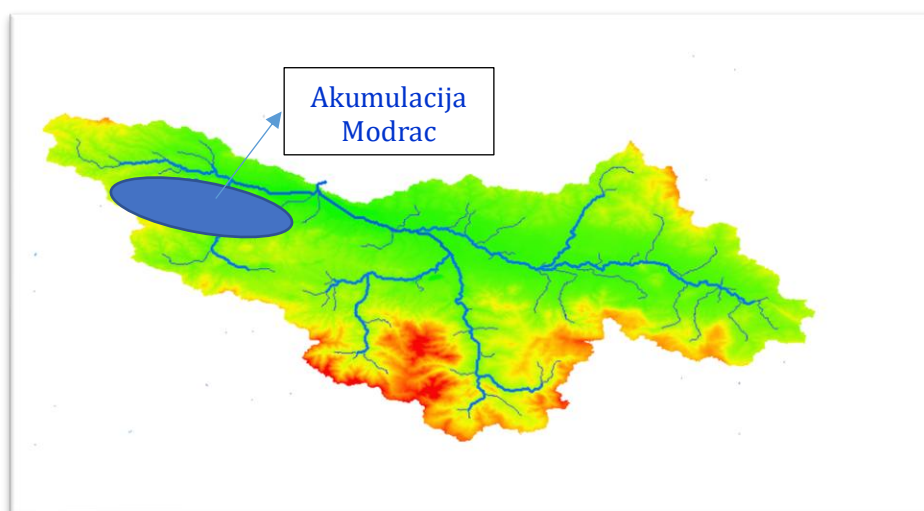


Figure 2. Map of the digital terrain model (DEM map) of the Modrac reservoir basin with river flows

The table below provides an overview of all recorded flood waves since the formation of the "Modrac" hydro reservoir until 2014 [7].

Table 1. Overview of flood waves from 1965 to 2014 [9]

The time of occurrence of the flood wave	Maximum level H	Inflow Q_{inf}	Discharge Q_{out}	Retention in the reservoir	Precipitation
	(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

Hydrograms of flood waves are determined on the basis of natural inflow into the reservoir. The discharge hydrogram is determined by the flow through the discharge facilities, the base discharges at the Modrac dam [10].

The flow is controlled via the flow curve at the downstream station Modrac.

The amount of discharge is regulated by lower discharges and overflow facilities and depends on the level of water in the reservoir. Given that the amount of flow is limited by the occurrence of large flood waves, the water level in the reservoir rises (accumulation charge), and thus absorbs part of the volume of the flood wave, i.e. reduces the maximum flow. The reduction of the maximum flow downstream ranges from 16% to 55% depending on the size of the water wave and the state of the Modrac reservoir level [9].

2. CHANGES IN PRECIPITATION AMOUNT

For a simpler overview of changes in the amount of precipitation for the period from 1999 to 2024, Figure 4. shows the maximum annual values of precipitation. Table 2 shows the mean annual precipitation values for the basin of the multi-purpose reservoir "Modrac" for the period 1999-2024.

Table 2 shows that the maximum value of average annual precipitation (1434 l/m²) was achieved in 2014. All data on precipitation were taken from the climatological station "Modrac" (Modrac rain gauge station), which is located at the Modrac Dam.

Table 2. Mean annual precipitation for the catchment area of the multipurpose reservoir "Modrac" for the period 1999 - 2024.

Year	P _{sum} (mm)	Year	P _{sum} (mm)
1999	903.00	2012	709.47
2000	403.40	2013	850.50
2001	1021.00	2014	1392.33
2002	746.30	2015	687.10
2003	781.10	2016	989.20
2004	1037.80	2017	843.85
2005	1133.20	2018	966.50
2006	1022.52	2019	896.90
2007	928.81	2020	915.60
2008	803.20	2021	814.00
2009	850.60	2022	820.32
2010	1258.10	2023	1030.58
2011	530.50	2024	673.25

3. INFLOW TO THE "MODRAC" HYDROACCUMULATION

At the tributaries of the "Modrac" reservoir, no flow measurements were made, that is, inflow into the reservoir, and the water inflow into the reservoir was calculated from the dependence of changes in the volume and amount of water released through the main outlets and overflows, using the water balance equation. Considering the fact that the input data were measured, the calculation can be considered sufficiently reliable.

Calculation of inflow and discharge of water is based on the following equations:

1. Water balance equation: $R = P - ET - IG - \Delta S$ (1)

where: P – precipitation

R – onflow

ET – evapotranspiration

IG – deep/inactive groundwater

ΔS – changes in material/deposit

2. Inflow and outflow equations using the water balance equation:

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

$$Q_{outflow} \cdot \Delta t = Q_{outflow} \cdot \Delta t \pm \Delta V \quad (3)$$

Where is:

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

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

Q_{inflow} – the amount of water flowing into the reservoir

$Q_{outflow}$ – the amount of water released from the reservoir,
 ΔV – the amount of water retained in the reservoir.

As an illustration, Figure 4 shows a typical diagram of mean annual precipitation in the reservoir, measured at the Modrac rain gauge station.

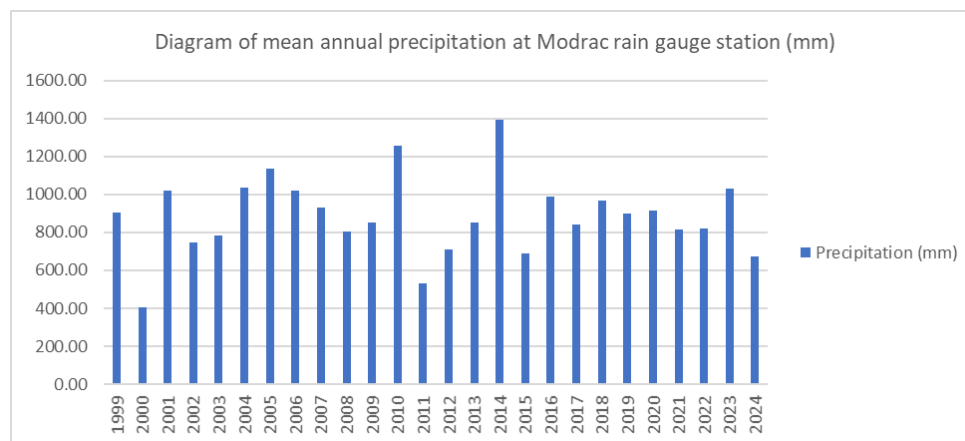


Figure 4. Diagram of average annual precipitation at the Modrac rain gauge station, from 1999-2024.

The following table shows the calculated values of the average annual inflows for the catchment area of the multipurpose reservoir "Modrac" for the period 1999 - 2024 (2).

Table 3. Average annual inflows for the catchment area of the multipurpose reservoir "Modrac" for the period 1999 – 2024.

Year	$Q_{inflow} (m^3/s)$	Year	$Q_{inflow} (m^3/s)$
1999	15.31	2012	9.53
2000	10.26	2013	12.83
2001	27.71	2014	15.98
2002	16.48	2015	16.03
2003	8.28	2016	13.48
2004	17.43	2017	14.88
2005	25.25	2018	17.10
2006	19.46	2019	15.02
2007	13.27	2020	15.51
2008	12.53	2021	8.48
2009	16.94	2022	11.78
2010	27.23	2023	17.02
2011	7.18	2024	9.28

4. COEFFICIENT OF RUNOFF FROM THE "MODRAC" ACCUMULATION BASIN

The average annual runoff coefficient η for the catchment area of the multi-purpose reservoir "Modrac" was calculated on the basis of data on the measured annual amounts of precipitation and the amount of water flowing into the multi-purpose reservoir and on the basis of the water

balance equation (1). Also, they are presented on an annual basis for the already considered period 1999 - 2024.

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

$$\eta = \frac{V_{runoff}}{V_{precipitation}} \quad (4)$$

Where is:

V_{runoff} – amount of water runoff (m^3)

$V_{precipitation}$ – rainfall (m^3)

Figure 5 shows the average runoff coefficient for the catchment area of the multipurpose reservoir "Modrac" for the period 1999-2024.

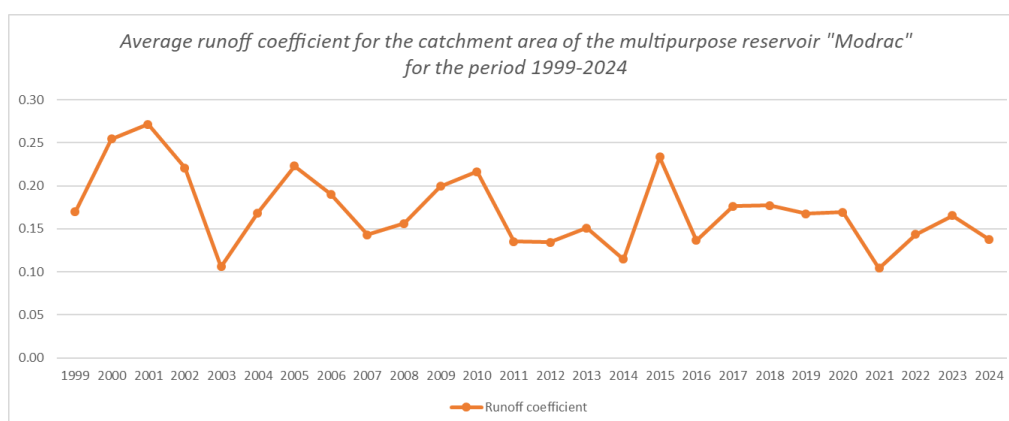


Figure 5. Average runoff coefficient for the catchment area of the multipurpose reservoir "Modrac" for the period 1999-2024.

In the continuation of the work, the functional dependence between the runoff coefficient and the calculated annual inflow (Q_{annual}) into the multi-purpose reservoir is shown (Figure 6) and the dependence of the runoff coefficient and the annual sum of precipitation P_{sum} (Figure 7) 1999 - 2024 is shown.

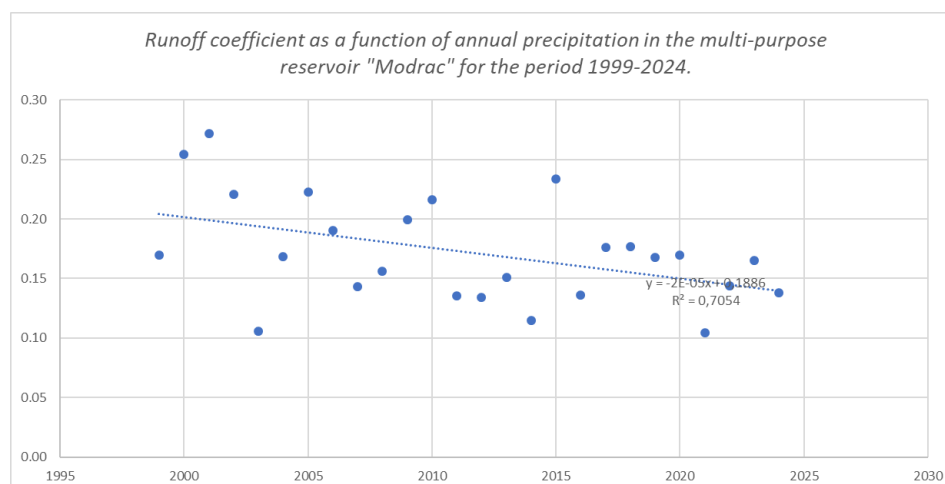


Figure 6. Runoff coefficient as a function of the mean annual inflow into the multi-purpose reservoir "Modrac" for the period 1999-2024.

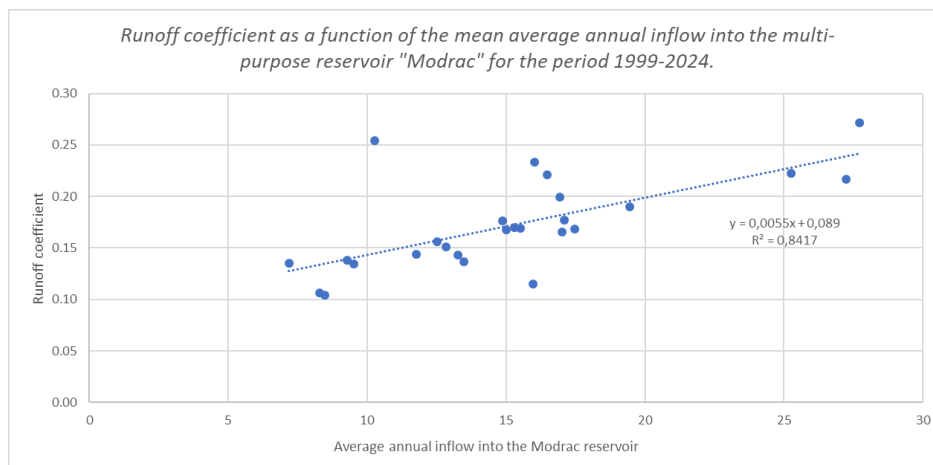


Figure 7. Runoff coefficient as a function of annual precipitation in the multi-purpose reservoir "Modrac" for the period 1999-2024.

CONCLUSION

This paper presents the runoff coefficient η in relation to the mean annual inflow into the multi-purpose reservoir "Modrac" and the annual sum of precipitation in the basin of the multi-purpose reservoir "Modrac" for the period 1999-2021. It is evident that the value of the correlation coefficient R in relation to the runoff coefficient and Q_{mean} annual average inflow is $R = 0.8417$, which is a very positive correlation (Figure 6), while in relation to the runoff coefficient and the annual sum of precipitation, the correlation coefficient is $R = 0.7054$, which represents a positive correlative mean (Figure 7).

Also, it should be noted that the value of the mean annual runoff coefficient for the catchment area of the multi-purpose reservoir "Modrac" for the considered period was the lowest in 2002, and the highest in 2004 (Figure 5).

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