

**ANALYSIS OF BACKFILLING BY SEDIMENTATION OF A MULTI-PURPOSE
RESERVOAR USING GIS MODELING ON THE EXAMPLE OF THE MODRAC
HYDRO RESERVOIR**

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Summary

Reservoirs are water management facilities that allow the regulation of the natural runoff regime. Depending on the natural characteristics of the hydrological system, the need for water and the volumetric capacity of the reservoir, and the characteristics of the evacuation organs, it is possible to manage the water resources of the basin. The increasing depletion of natural water resources and the increasing problems with meeting water needs have emphasized the need for the construction of reservoirs, often with multi-year equalization, as an integral element of integrated water resources management. Water resources management includes a number of activities such as planning, design, construction, management, maintenance, monitoring and control of constructed facilities, in order to assess and increase their efficiency. Accordingly, it is necessary to specifically plan all activities in relation to reservoirs as key facilities for managing the water regime of a basin.

Keywords: multipurpose reservoir, water resources, sediment, catchment area, sedimentation, GIS modeling

1. INTRODUCTION

The Modrac reservoir is the only available water resource in the Tuzla region and its surroundings. Bearing in mind the fact that the useful volume of the reservoir is limited, and that over time the reservoir is filled with hauled sediment and coal dust as floating sediment, and that consumers - the population, industry and others - must be provided with a water supply with a high degree of safety. Surplus water needs to be used to the maximum for the purpose of electricity production, and there is a need to optimize the system, i.e. more efficient management of the water resource of the reservoir, i.e. to prove the maximum utilization of the reservoir while constantly providing all the necessary amounts of water to which the Modrac reservoir is connected [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 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 [1].

With increasing and often conflicting requirements for the use of water resources, there is a need for more complex management methods, including reservoir volume management.

In some reservoirs, already 10-20 years after their construction, the sediment volume reaches 20-30% of the general volume of the reservoir [2].

The purpose of the assessment of the transfer of sediment to the hydroaccumulation is to realize the possibility of more effective management of natural water resources, protection from the harmful effects of water, as well as protection of water from pollution.

By analyzing the sediment transport at the inflow, and the total amount of sediment deposited in the Modrac reservoir, real data are obtained about the amount of sediment introduced into the Modrac reservoir, the dynamics of sediment input, and the degree of pollution of this type of water body.

2. GIS MODELING

A geographic information system (GIS) is a system for managing spatial data and the attributes associated with it. In the strictest sense, it is a computer system capable of integrating, storing, editing, analyzing and displaying geographic information. In a general sense, GIS is a "smart map" tool that allows users to create interactive questionnaires, analyze spatial information, and edit data. One of the oldest definitions of GIS is:

"GIS is a special type of information system in which the computer database includes precisely defined relationships between spatially distributed objects, activities and events, which are spatially defined as points, lines and surfaces (polygons) [3].

In GIS, the data are related to these points, lines and polygons and are thus stored for research and analysis" [3].

Modeling of the catchment area of the multi-purpose reservoir was done in the ArcGIS software package, in which all foundations and input data for the calculation were prepared, modeling of the Modrac reservoir basin and hydrological hydraulic calculation was done in ArcSWAT. In the mentioned software on the geoinformation platform (GIS) the results were obtained: the flow of the main watercourses in the catchment area of the Modrac reservoir, the saturation of the soil and the transport of sediments in the rivers and their transport to the Modrac reservoir.

3. INPUT DATA FOR THE MODEL

The input data for modeling in the ArcGIS software package, or in the GIS tool – ArcSWAT, are:

- digital terrain model,
- map of the catchment area's surface use,
- map of the pedological composition of the catchment area's soil,

- hydrometeorological data (precipitation, temperature, wind, solar insolation and air humidity).

The following figure (Figure 1) shows how the ArcSWAT software works, the required substrates and substrate analysis, and the results obtained with this approach to watershed research.

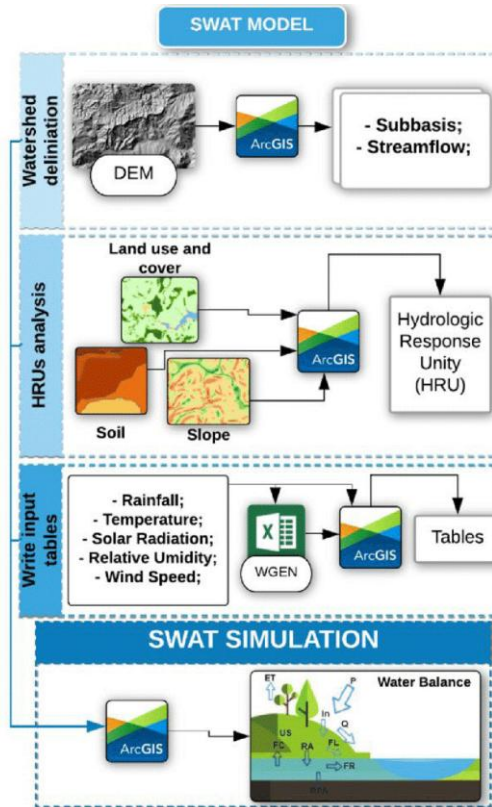


Figure 1. Presentation of the mode of operation of the ArcSWAT model [3]

The digital terrain model as one of the most important bases was downloaded from USGS Earth Explorer, the data of the digital terrain model is SRTM 30 m. SRTM 30 m is a file containing digital elevation data for an international research program, which produced digital elevation models at the global level.

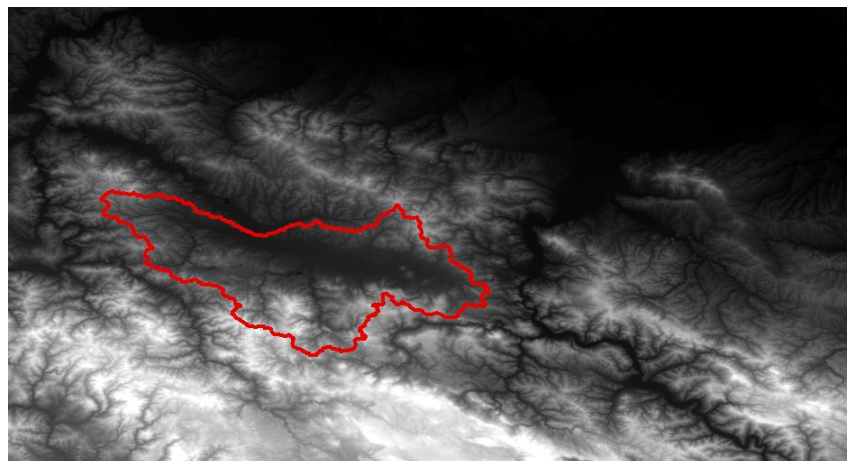


Figure 2. Digital terrain model of the wider area with the drawn boundary of the Modrac reservoir catchment area

The **land use and land cover map** is also a digital data map and a necessary basis for the analysis of the catchment area and for the calculation in the mentioned software package. The resolution of this map is quite high, and as of 2020 it is 10 m.

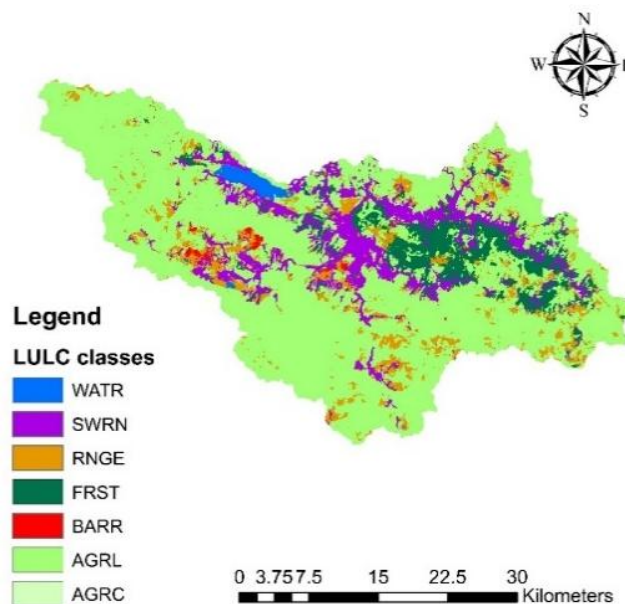


Figure 3. Land use and land cover map

Bearing in mind the available input data that are necessary for the modeling of the catchment area, in this work, data on the amount and transport of total suspended sediment were compiled for a series of 8 years, from 2014 to 2021.

The soil map is also a map with digital data and a necessary basis for the analysis of the catchment area and for the calculation in the software package ArcGIS, or ArcSWAT. For the region in question, to which the Modrac reservoir basin belongs, the soil map with pedological characteristics was taken from www.fao.org, which contains a database on pedological soil characteristics at the global level [4].

The above map contains databases related to data and maps compiled using field research supported by remote sensing and other environmental data, expert opinion and laboratory analyzes [4].

Figure 4 shows the soil map of the Modrac reservoir basin according to the dominant soil classification. The catchment area of the Modrac reservoir is dominated by three dominant soil types, namely:

- Rankers (U3-2c) indicates shallow rocks with solid or fragmented non-calcareous rocks;
 - Luvisol (Lg43-2ab) are soils associated with short-term water saturation in the profiles;
- and
- Cambiosols (Bd66-1/2bc), are widespread soils developed on different lithologies that play a significant role in the pedological development of this relatively young soil [4].

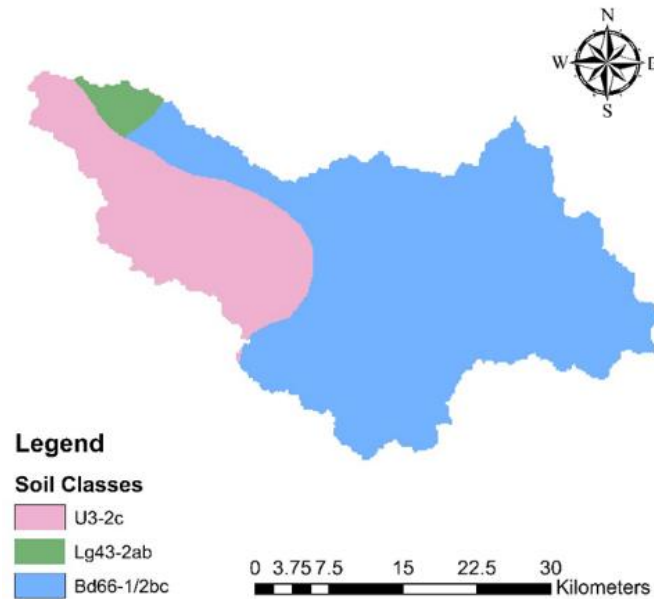


Figure 4. Soil map of the Modrac reservoir basin by dominant soil classification

Hydrometeorological data are also used as a basis for analyzing the catchment area and obtaining results about the flow in watercourses (inflow into the Modrac reservoir), sediment transport, soil saturation, nutrient input into the reservoir (organic load). Hydrometeorological data were taken for a series of 8 years (2014 - 2021) from Modrac rain gauge station.

4. MODELING RESULTS

In this paper, time steps (monthly as well as daily) were used to evaluate the SWAT model. Different evaluation parameters were used to evaluate the models and their performance as recommended by Moriasi et al. (2007), i.e.:

1. Nash–Sutcliffe efficiency (NSE),
2. graphic technique using hydrographs,
3. standard RMSE observation deviation ratio (RSR) i
4. percentage bias (Pbias).

In addition, the index of agreement (D) and coefficient of determination (R²) were also calculated and compared for all results obtained by modeling in SWAT software. The terrestrial part of the hydrological cycle is based on the water mass balance. Hydrological processes and the application of the SWAT model are simulated daily for each HRU - hydrological unit, in time steps using the following soil water balance equation [5].

$$SW_t = SW_0 + \sum_{i=1}^n (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \quad (1)$$

where:

SW_t – total water content in the soil (mm)

SW_0 – initial water content in the soil (mm)

R_{day} – amount of precipitation per day (mm)

Q_{surf} – amount of surface runoff per day (mm)

E_a – evapotranspiration per day (mm)

w_{seep} – amount of percolation (extraction) – raising the groundwater level (mm)

Q_{gw} – amount of groundwater (mm)

The Penman-Monteith method of real evapotranspiration as well as potential transpiration is used for the calculation. Modified method CN curves with a modified rational method are used to calculate surface and peak runoff [6].

The universal equation of soil erosion and amount of sediments was defined by Williams in 1995 [7]:

$$sed = 11,80 \times (Q_{surf} \times q_{peak} \times area_{hru})^{0,56} \times K_{usle} \times C_{usle} \times LS_{usle} \times CFRG \quad (2)$$

where:

sed – amount of sediment (t/dan)

Q_{surf} – surface runoff volume (mm)

q_{peak} – peak surface runoff rate (m^3/sec)

$area_{hru}$ – hydrological unit area HRU (ha)

K_{usle} – soil erosion factor (taken: 0.013 t/ha)

C_{usle} – land cover and management factor

LS_{usle} – topographic factor

CFRG – coarse fragment factor.

Below are graphical results from the SWAT model in diagrams showing the relationship between precipitation as input data and sediment quantities as the result of this analysis.

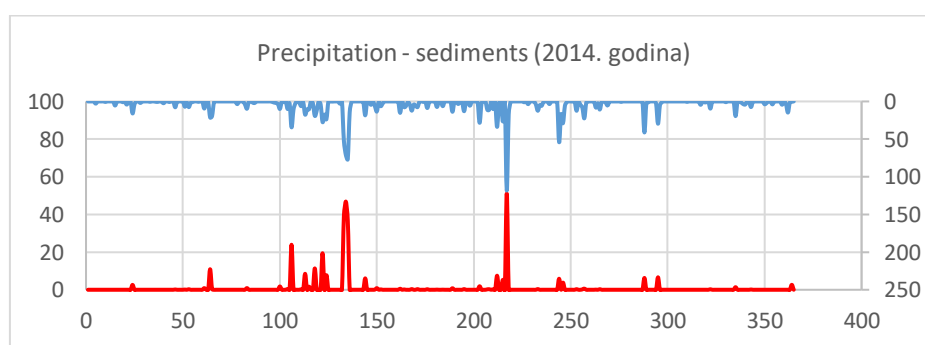


Figure 5. Diagram of precipitation and sediments in 2014

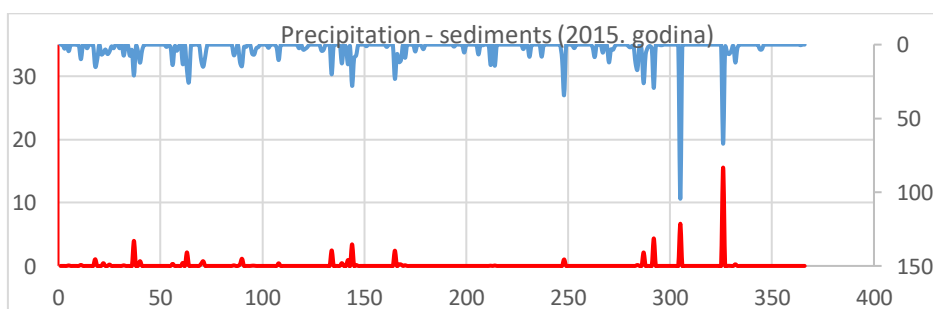


Figure 6. Diagram of precipitation and sediments in 2015

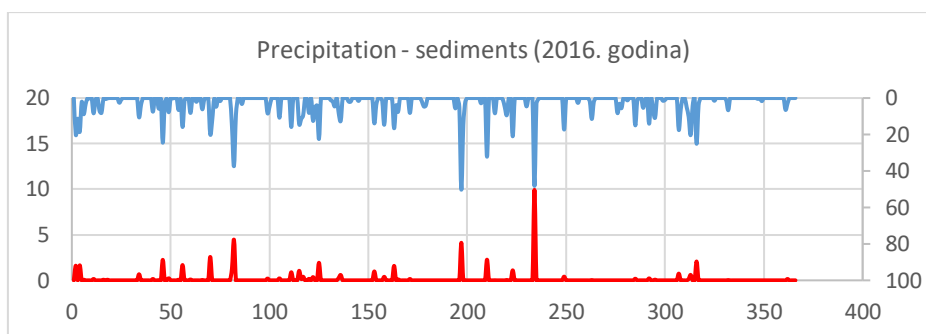


Figure 7. Diagram of precipitation and sediments in 2016

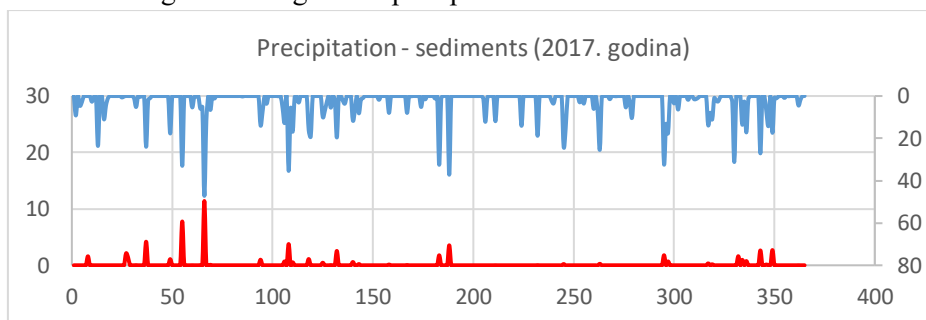


Figure 8. Diagram of precipitation and sediments in 2017

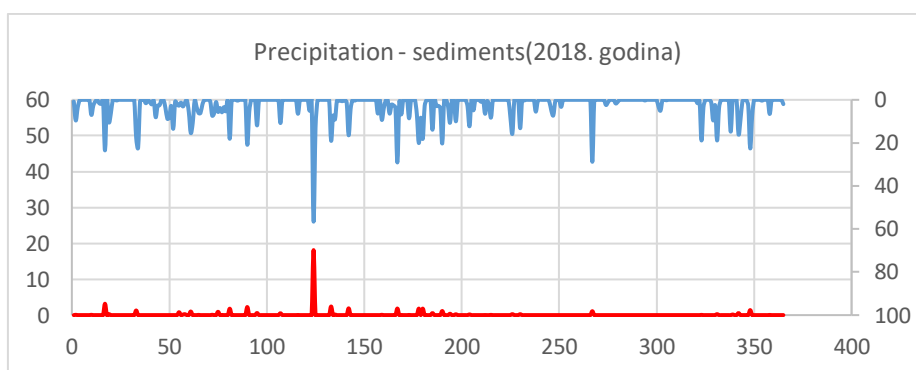


Figure 9. Diagram of precipitation and sediments in 2018

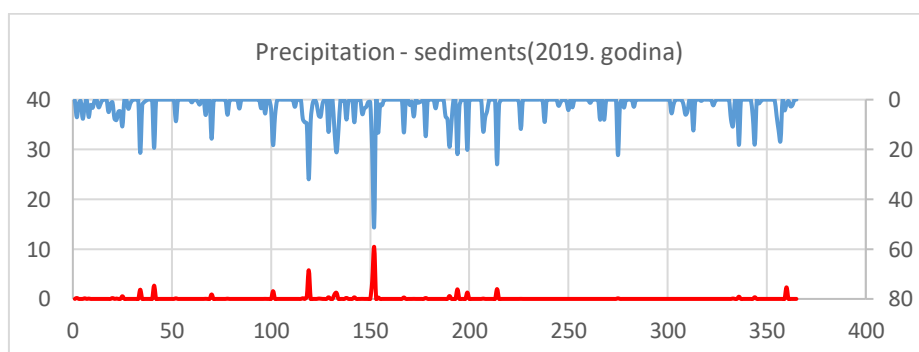


Figure 10. Diagram of precipitation and sediments in 2019

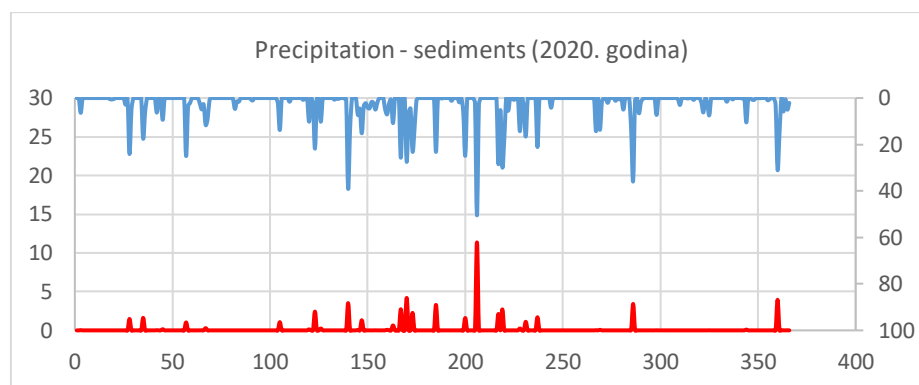


Figure 11. Diagram of precipitation and sediments in 2020

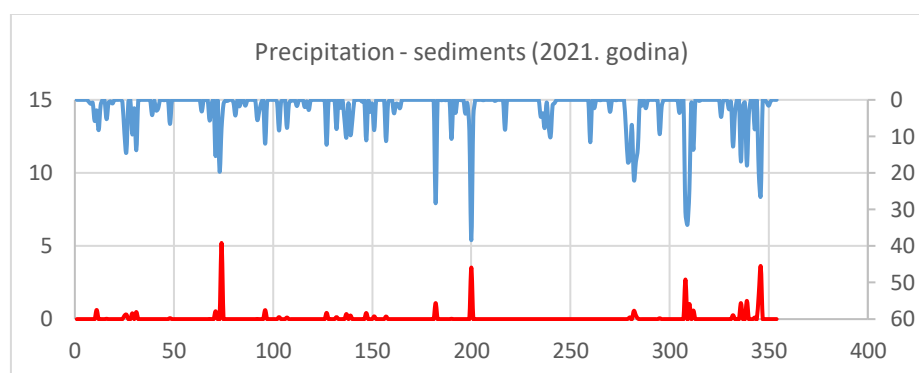


Figure 12. Diagram of precipitation and sediments in 2021

For the results obtained for the period 2014 - 2021, correlation and simple regression were performed, the relationship between precipitation and sediments (sediment), their mutual relationship shown through the Pearson coefficient R^2 . The stated Pearson coefficient R^2 is tabulated for the period 2014-2021 [8].

Table 1. Tabular presentation of Pearson coefficient R^2 for the period 2014-2021

Year	Average annual precipitation (mm)	Amount of sediment (deposit) t/ha	Pearson coefficient R^2
2014	1430,20	319,62	0,9527
2015	870,80	47,06	0,9348
2016	989,20	48,78	0,9248
2017	982,90	58,40	0,9593
2018	966,50	48,46	0,9369
2019	896,90	41,76	0,8643
2020	915,60	55,08	0,8935
2021	814,00	28,89	0,7366

CONCLUSION

This paper presents the modeling of the catchment area of the "Modrac" reservoir with GIS tools. In relation to the input data, the value of the daily amount of sediments (sediment)

introduced into the "Modrac" reservoir was obtained. Correlation of precipitation as an input data and the amount of sediment as a result of this analysis, the Piroson coefficient R^2 is given, which describes their mutual connection. It is important to point out that the R^2 coefficient for 2014 is 0.9527, which is a very large positive relationship, as well as for other years in the given period. The highest Pearson coefficient was read in 2017 and is 0.9593, and the lowest in 2021, which is 0.7366 (Table 1).

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