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Analysis of SHPP Brodraci influence on production of HPP Ozalj

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Abstract
Hydro junction Brodarci on the river Kupa is part of flood protection system Srednje Posavlje focusing to protect the city of Karlovac. Final design of flood protection system includes utilisation of hydropower in form of small hydropower plant Brodarci (SHPP Brodarci). In this paper an analysis of the impact of the SHPP Brodarci backwater on the production of existing hydropower plant Ozalj (HPP Ozalj) is given. Within the analysed river reach is located confluence of tributary river Dobra. HPP Lešće operation on river Dobra affects the regime of the river Kupa between the SHPP Brodarci and HPP Ozalj. Available hydrologic data includes information from gauging stations on river Kupa upstream and downstream of analysed river reach and on river Dobra downstream of HPP Lešće. Assessment of HPP Ozalj's tailwater in the design state is based on the results of a detailed hydraulic flow model setup on hourly data and operating conditions on both HPP. Also are available hourly data for the year 2012 on production, the tailwater and the headwater at HPP Ozalj. For better description of the real conditions of production and thus a more accurate assessment of the impact efficiency curve for HPP Ozalj is analysed in detail. The main idea was to determine efficiency coefficient depending on available flow and head. Conducted analyses resulted in comparison of HPP Ozalj's production in the current and design state based on the defined hydrological regime and efficiency curve. Results show that the raising tailwater during low flow has no negative effect on the production of HPP Ozalj due to improved working conditions and increased efficiency coefficient.

Keywords
small hydropower plant, efficiency curve, backwater impact

1. INTRODUCTION

The subject of this paper is to determine the impact of future small hydropower plant (SHPP) Brodarci on Kupa, near the entrance to 21,9 km long flood relief channel Kupa-Kupa, on production of hydropower plant (HPP) Ozalj placed upstream. Primary design of SHPP Brodarci defines it as a run of the river HPP with installed discharge of 120 m^3/s and generating capacity 2.8 MW at gross head of 4m (headwater at level +112,00 m asl (above sea level)). This location in flood protection system of city of Karlovac is named hydro junction Brodarci and it redirects high waters of River Kupa to channel Kupa – Kupa. Around 700 m upstream from the channel Kupa – Kupa, river mouth of r. Dobra can be found. HPP Lešće on r. Dobra is also included in the analysis. It is placed 30 km upstream of SHPP Brodarci with installed discharge of 120 m^3/s).

2. INPUT DATA ANALYSIS

The most interesting part of the analysis is defying the efficiency coefficient depending on head and discharge based on inputs. The SHPP Brodarci impacts the tailwater of HPP Ozalj. As shown in Table 1 there is only data on efficiency coefficient for one turbine depending on discharge. Efficiency coefficient, used in analysis, is defined based on data on heads, production of turbines and hourly discharges.

Tab 1. Review of database used in the analysis

Survey	Hydrologic data	Data from HPP Ozalj
Croatian Base Map 1:5000	HPP Ozalj: water levels (headwater, tailwater – hourly data)	Data on production of HPP Ozalj for 2012 in form of daily reports with hourly data
Topographic map of Croatia 1:25000	Gauging station Kamanje: water levels (daily data); discharge-water level curve	efficiency coefficient of turbine depending on discharge for 1 turbine
Channel bathymetry data	Gauging station Brodarci (r. Kupa): hourly data discharges and water levels	
	Gauging station Stative donje (r. Dobra): hourly data discharges and water levels	

Figure 2 shows „input data“ used in the analysis based on data from turbine producer (marked with green) and efficiency coefficient according to calculations made based on data from HPP Ozalj (marked with blue). The Figure 2 also shows a clear need for detailed analysis, which would estimate the effect of head decrease on production at small discharge. The problem that appears when analysing efficiency coefficient is that a wide range of efficiency coefficient appears in similar conditions.

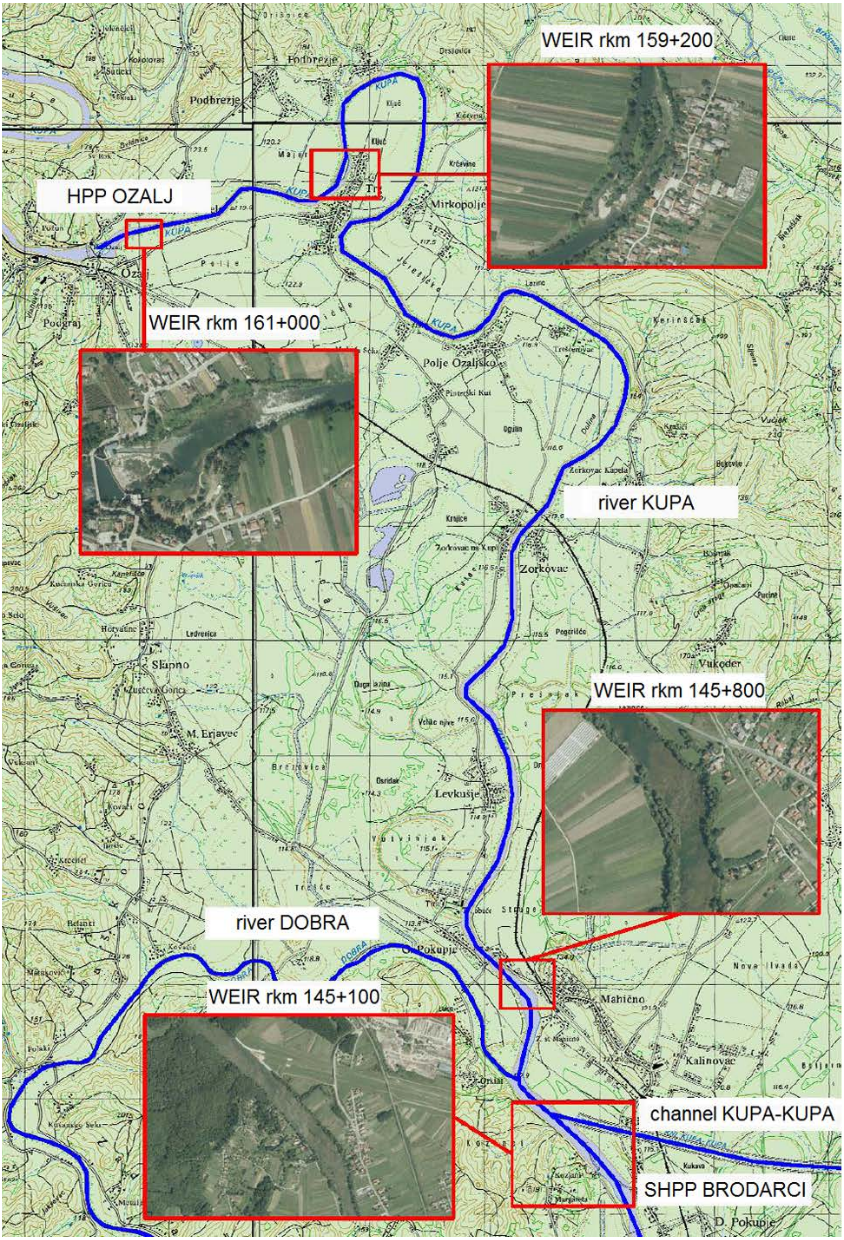

Fig. 1 General layout of analysed river section

The mathematical method of approximation and averaging oscillations is used to create efficiency coefficient used in further analysis (figure 3). The data was fitted using polynomial regression, resulting in 3d curve which fits the efficiency coefficient in the dependency of two input variables – discharge and gross head. In the manner of showing clear representation, the efficiency coefficient curve is represented using equipotential lines, in figure 3. It should be noted that further in paper term efficiency coefficient involves efficiency values of the power plant including the loss of the water turbine, generator and transformers of all turbines in operation at any discharge.

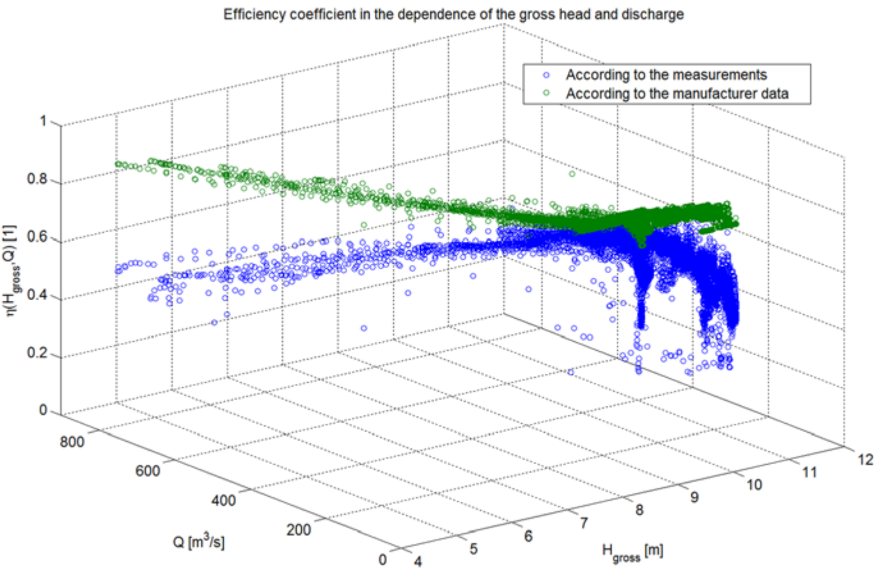

Fig. 2 Efficiency coefficient HPP Ozalj depending on head and discharge

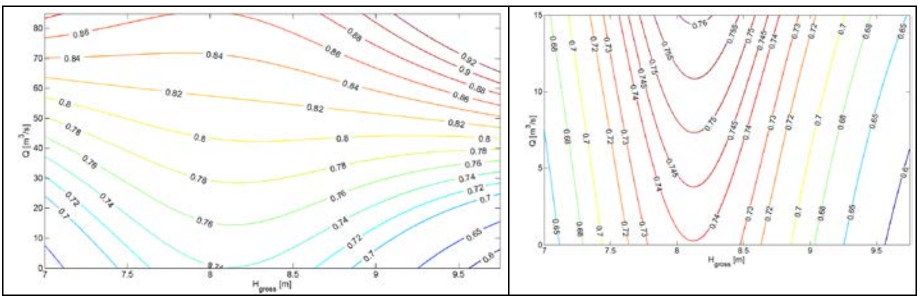

Fig. 3 Efficiency coefficient HPP Ozalj depending on head and discharge used in this paper

Hydraulic flow model is made as the basis for determine impacts of SHPP Brodarci on hydraulic regime of River Kupa in order to estimate the impacts of SHPP Brodarci on production of HPP Ozalj more precisely. Hydraulic flow model for current and future state was made with HEC-RAS. The model included r. Kupa from river station 144+900 (SHPP Brodarci) to river station 161+772 (HPP Ozalj tailwater) and r. Dobra from river mouth into Kupa (river station 145+700 Kupa) to river station 11+210 (gauging station Stative donje). The accuracy of calculations made by numerical model depends on the accuracy of used river geometry and hydrological boundary conditions. Calibration of the numerical model is reduced to the determination of the roughness coefficient and weir overtopping coefficients which affect the hydrological regime of the river Kupa and Dobra. Calibration is carried out on the basis of available data of the hydrological boundary conditions on the boundaries of the model - the water level and flow at Brodarci, Ozalj and Stative donje.

Based on the calibrated model, the calculation of the flow of the rivers Kupa and Dobra was made for current state with discharges from yr. 2012. Discharge range for r. Kupa was from 5 m^3/s to 834 m^3/s according HPP Ozalj input data, and from 9,5 m^3/s to 1006 m^3/s at gauging station Brodarci. Discharge range for r. Dobra at gauging station Stative donje was from 3,1 m^3/s to 240 m^3/s.

The input data analysis are divided into two input data subsets according to the dependence on the work of HPP Lešće: the data with the impact of the HPP Lešće and the data when HPP Lešće was not in operation.

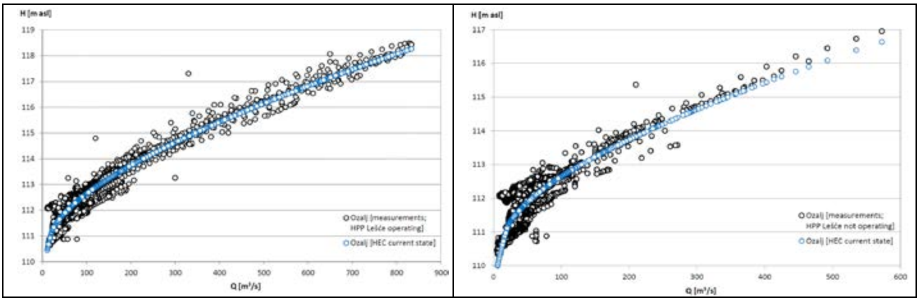

Fig. 4 Hourly flow and water levels from the input data (black) and the results of the numerical model (blue) at HPP Ozalj tailwater: HPP Lešće in operation (left) - HPP Lešće not in operation (right).

It is evident that the results of numerical models at location of the HPP Ozalj tailwater correspond well with the measurements. As shown in figure 4, the results of the model are in the middle of a cloud of oscillating water levels from measurement.

Results of numerical model for future state with headwater on SHPP Brodarci on level +112,00 m asl are shown in figure 5. These results are used to analyze changes in the hydrological regime of the river Kupa and Dobra in the case of construction of SHPP Brodarci. The results are presented for the current and future state for two cases – HPP Lešće in operation and HPP Lešće not in operation. Figure 5 shows discharges in the zone of interest for the production of HPP Ozalj. The impact of the HPP Lešće is clearly visible with increase of the water level up to 30 cm.

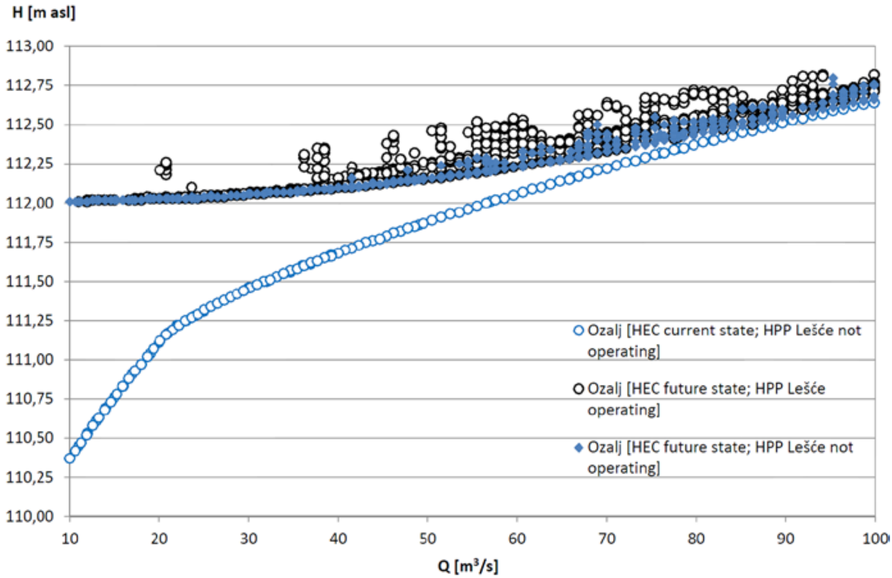

Fig. 5 HPP Ozalj tailwater in current and future state at lower discharges (below installed discharge)

Finally, Figure 6 shows the impact of the SHPP Brodarci backwater on HPP Ozalj depending on the discharge rate which is in the range of 2 m at an extremely small discharge (5 m^3/s), approximately 1.5 m at a discharge of 10 m^3/s, 1.0 m at a discharge of 20 m^3/s, 60 cm at 30 m^3/s, 40 cm at 40 m^3/s, 10 cm at the discharge of 70 m^3/s. At a discharge of around 150 m^3/s impact is completely lost in case when HPP Lešće is not in operation. But in the case when HPP Lešće is operating impact still exists, but due to the short duration through the year, doesn't have significant impact on production.

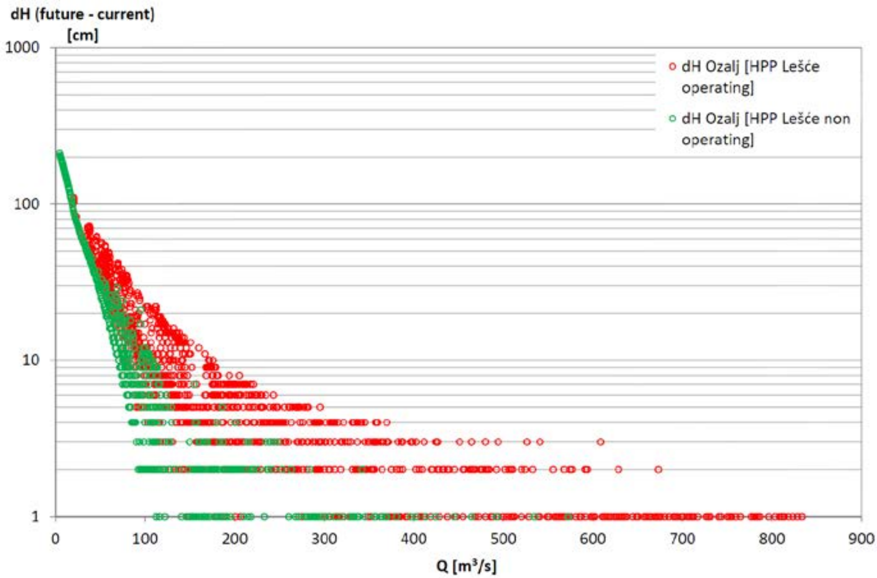

Fig. 6 SHPP Brodarci backwater impact on HPP Ozalj

3. IMPACT ON HPP OZALJ ENERGY PRODUCTION

Based on the results of the numerical model for the current state, an analysis of future production by the same criteria was made. Namely, before the use of numerical model results for the future state it is necessary to prove its applicability to the current state. For this reason the results of the numerical model for the current state were verified by comparing the actual production from 2012 and production on the base of numerical model water levels and efficiency coefficient shown in figure 3.

Calculation of production was carried out for two cases. As the first, to check the results of hydraulic models and in the paper defined efficiency coefficient, production in the current state was calculated. After that, production in the future state on the basis of numerical model was calculated. Calculation of energy production was carried out according to the equation:

$$W = 9{,}81 \cdot Q_r \cdot H_b \cdot t_r \cdot \eta, \tag{1}$$

where: W (kWh) is energy production, Q_r (m^3/s) is discharge, H_b (m) is gross head, t_r (h) is discharge and associated gross head duration, η (1) is efficiency coefficient (turbine, generator, transformer, hydraulic loss in penstock).

The maximum used discharge is 85 m^3/s, although according to the data from HPP Ozalj can be concluded that HPP Ozalj occasionally worked with a larger discharge.

The results obtained by the procedure described above are shown in Table 2.

Tab 2. HPP Ozalj production

	2012. yr Input data from HPP Ozalj	**2012. yr numerical model for current state**	**2012. yr numerical model for future state**
Production [GWh]	22,356	22,309	22,248

According to the presented results it can be seen that the deviation in the HPP Ozalj production in the current state (from numerical model) compared to measured data is less than 1 %. That shows that numerical model and efficiency coefficient were determined correctly. Furthermore, production in future state doesn't change much because, as expected, increasing HPP Ozalj tailwater also increases the efficiency coefficient. In that case with smaller gross head at small discharges production stays almost the same.

4. CONCLUSION

In this paper, an analysis of the impact of future small hydropower plant Brodarci on the production of HPP Ozalj was made. For a better description of the real conditions of production and thus a more accurate assessment of the impact, hourly data obtained from HPP Ozalj on production, headwater and tailwater and average daily discharges were used.

SHPP Brodarci, designed as run of the river SHPP with headwater at +112 m asl, obviously has impact on upstream located HPP Ozalj tailwater. Based on the collected data the HPP Ozalj efficiency coefficient depending on discharge and gross head is determined.

Finally, a comparative calculation of production in the current and future state (according to numerical flow model) were obtained. Analysis shown in the paper confirmed that the development of hydro junction Brodarci with SHPP Brodarci will not have a significant negative impact on the production of HPP Ozalj.

5. REFERENCES

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