HYDROLOGICAL ANALYSIS OF FLOW VARIATIONS ON SHPP SITE

Gordon Gilja[1], Eva Ocvirk[2] and Boris Beraković[3]

Abstract

The use of renewable energy resources is greatly encouraged by many governments, with aim for achieving sustainability whilst satisfying ever-growing demand for energy consumption. Among the renewable resources of energy in the world, hydro power plants produce the most electric energy. Small hydro power plants (SHPP) partake in overall hydro power production with around 7% of installed power (approx. 50 GW). Of special interest for small hydro power plants are sites where in the past water power and energy was used, particularly from standpoint of environment acceptability and regional and country planning. According to the regulations in the energy sector: "Besides the Croatian national electricity company (HEP), persons, companies and other legal persons can also produce and distribute electric power". Currently third of the small hydro power plants in Croatia are in private ownership, and trend of private investments is showing continuous growth as investors see possibility for good rate of investment return. Installed power for 95 % of available locations is less than 1 MW. On these watercourses variety of flow conditions can occur which are poorly recorded because of monitoring network scarcity. This paper covers hydrological analysis of the Lika River for location of small hydro power plant Miškulin near the city of Gospić. The Lika River is torrential stream with zero-flow period during dry season and is influenced by considerable backwater from reservoir Kruščica during rainy season. Hydrology at SHPP site is under influence of the Lika River's four tributary streams. This example illustrates method for analysis of sites under extremely temporally and spatially variable hydrological conditions.

Keywords

Renewable energy resources, small hydro power plant, the Lika River

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1 INTRODUCTION

The hydro power plants can be categorized in many ways – by type of the turbine, size, installed power, etc. Small hydro power plants (SHPP) are plants with an installed power smaller than the limit, which varies from state to state (in Croatia small hydro power plants are those from 500 kW to 10 MW of installed power). In the European Union and in the most countries of the world upper limit for SHPP is 10 MW. Small hydro power plants are becoming increasingly important in the power systems of the developed countries [1]. There are number of plants built all over the world and because of the good experiences in building and working the interest for them is increasing, as shown in table (Table 1). There were more than 60000 small power plants in the world in 2002.

Table 1. Summary of SHPP use in Europe.

Country	***Installed power (MW)***	***No of SHPP***
Austria	670	1720
Czech rep.	200	1200
France	1972	1717
Germany	1300	6000
Italy	2000	1510
Norway	950	550
Spain	1540	/
Sweden	1050	1615
Switzerland	750	1000
Croatia	73.2	32

Among the renewable sources of energy in the world, hydro power plants produce the most electric energy. The potential for the total installable power of SHPP is estimated to be about 180 GW, which is about 6 % of the estimated total installable power in hydro power plants [2]. Europe ranks second in energy contribution from SHPP on global level, following Asia. In year 2001 SHPP contributed approximately 2 % in total energy production, and 9 % in energy production from renewable resources [3, 4]. In 1985 Republic of Croatia published *Croatian Register of Small Streams* which gave the first assessment of possible SHPP locations on 134 streams. More detailed study declared 63 streams from afore-mentioned 134 as suitable for construction of small hydro power plants. On those 63 streams 699 locations were identified, with total installed power about 177 MW (Table 2).

Table 2. Summary of potential SHPP locations in Croatia by installed power.

Installed power (MW)	***No of SHPP sites***	***Total installed power (MW)***
1.5 - 5	20 (3 %)	50.2 (29%)
1 – 1.5	17 (2 %)	21.7 (%)
0.5 – 1	42 (6 %)	28.7 (%)
0.1 – 0.5	296 (42 %)	55.7 (%)
< 0.1	324 (47 %)	20.7 (%)
Total	699	177

Number and availability of potential SHPP sites is inversely dependant of installed power, because smaller natural drops are more common than bigger ones [5]. Croatian watercourses are characterized by large number of small drop sites, with more suitable sites located in upper part of basin – remote and populated areas with insignificant power consumption and scarce distributive network, as well as natural landscape areas. Most of the small hydro power plants are in private ownership –restored water mills built and operated throughout history and abandoned during early 20th century. This paper presents hydrological analysis and energy production determination for SHPP Miškulin situated on Lika River in upper part of reservoir Kruščica which is a part of HPP Senj. Water stage oscillations in reservoir are between 30 m and 60 m what are reflected in upper part of reservoir. The idea is to better use of Lika river energy with SHPP, which will operated in specific circumstances and what cause specific hydrological and hydraulically analyses.

2 HYDROLOGICAL DATA

SHPP planning consists of determining tailwater elevation, headwater level and backwater effect on upstream river reach and floodplains. Since SHPP sites are rarely located at gauging stations these values are calculated using 1D numerical flow model of range of hydrological events. Flow model is defined with 37 cross-sections, with downstream boundary condition set on gauging station GS Budak and upstream boundary condition set on GS Bilaj (both on Lika River). Hydrological regime on defined river reach is influenced by several factors: discharge of Lika River, inflow from tributaries Jadova River (upstream of SHPP site) and Novčica River (downstream), as well as backwater generated from Kruščica reservoir situated 50 km downstream (**Fig. 1**). Discharge at SHPP site is sum of Lika River flow (GS Bilaj) and flow from tributary Jadova (GS Barlete).

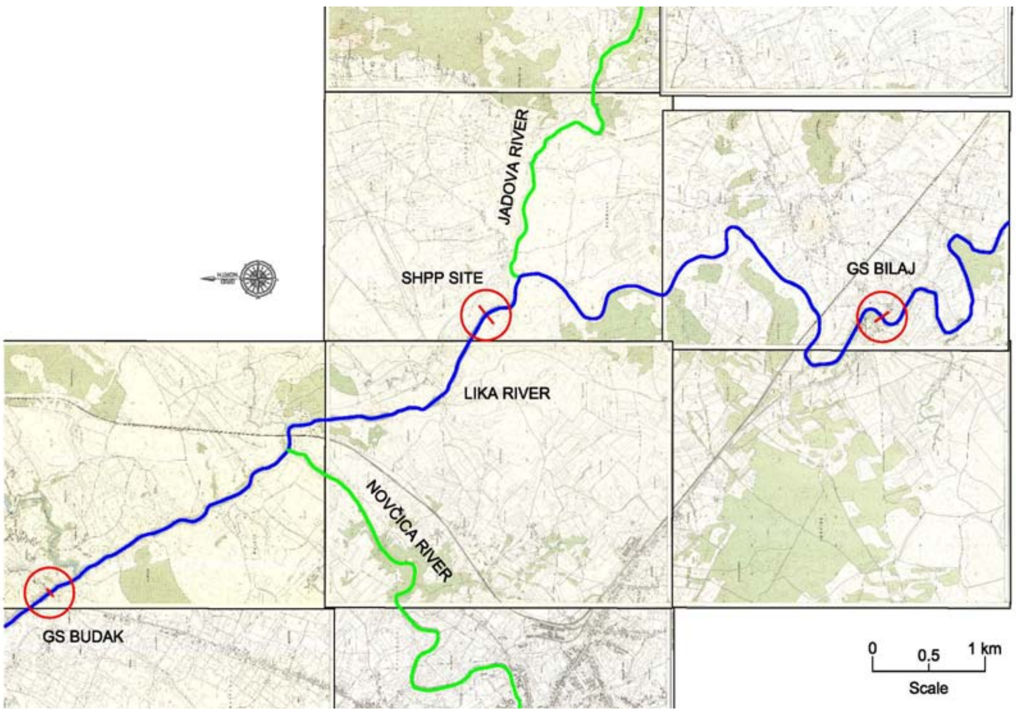

Fig. 1 Modelled river reach with location of boundary condition profiles, tributaries and SHPP site.

Downstream of SHPP site flow conditions are unfavourable because of inflow from tributary Novčica River (calculated from GS Lički Novi on Novčica River and GS Kolakovica on Bogdanica River - Novčica's tributary). Downstream boundary condition of flow model is GS Budak on which only stage hydrograph is recorded, discharge curve cannot be established because of significant backwater effect from Kruščica reservoir (**Fig. 4**). Discharge on GS Budak is thus calculated as sum of Q_{BILAJ}, Q_{JADOVA}, $Q_{NOVČICA}$ *and* $Q_{BOGDANICA}$. Next figure (**Fig. 2**) shows hydrographs for all GS in year 2004. Hydrological regime of rivers with small watersheds usually results in low median discharges with extremely large ratios of peak and low discharge. Mean and maximum discharges are given in following table (Table 3).

Table 3. Characteristic discharges for Lika River and its tributaries.

	Q_{LIKA}	Q_{JADOVA}	$Q_{NOVČICA}$
Q_{MEAN}	5.6	3.4	4.7
Q_{MAX}	145	103	117.3

There is visible dry season from June till October, with no flow during August and September, while peak discharges occur during winter and spring.

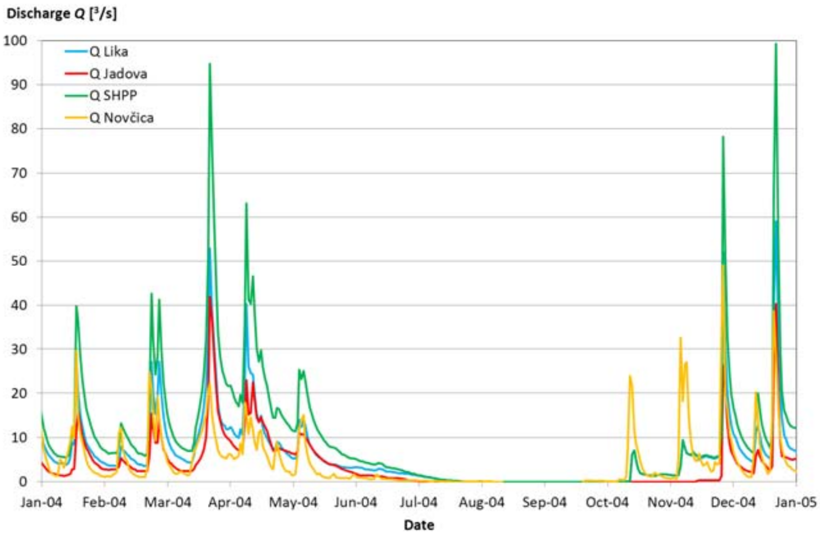

Fig. 2 Flow hydrographs for Lika River and its tributaries in year 2004.

3 HYDROLOGICAL ANALYSIS

In order to establish boundary conditions for analysis of hydrological regime, correlation between discharges of Lika River and its tributaries must be defined for range of discharges. For discharge correlation analysis base station used is GS Bilaj (upstream boundary condition) and time period from 2003 to 2011. Discharge on all GS is correlated with GS Bilaj discharge Q_{BILAJ} with goal to define relationship between them. Since seasonal variation of discharge on defined river reach is pronounced (**Fig. 2**) there is no significant correlation between Q_{BILAJ} – $Q_{NOVČICA}$ (R^2 = 0.77) In order to define discharge correlation more accurately year is divided in 6 periods: period G1 (January and February), period G2 (March through May), period G3 (June and July), period G4 (August), period G5 (September and October) and period G6 (November and December).

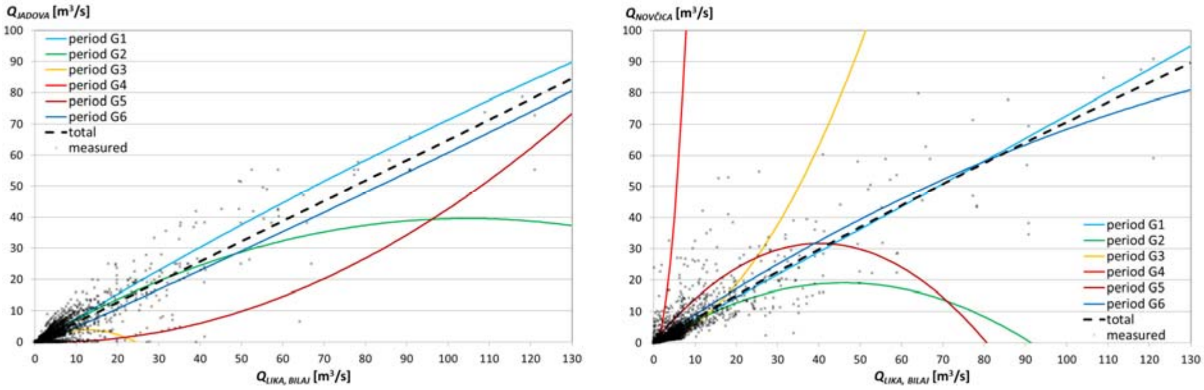

Fig. 3 Discharge correlation between Q_{BILAJ} and tributary: a) Jadova River; b) Novčica River.

Scatter plot given for discharge correlation shows that correlation strength for different periods varies (Table 4).

Table 4. Coefficient of determination from discharge correlation analysis.

Period	R^2 $Q_{JADOVA}=f(Q_{BILAJ})$	R^2 $Q_{NOVČICA}=f(Q_{BILAJ})$
G1	0.92	0.80
G2	0.70	0.64
G3	0.74	0.58
G4	0.04	0.77
G5	0.76	0.57
G6	0.84	0.78
total	0.85	0.77

There is visible strong correlation between discharge Q_{BILAJ} and Q_{JADOVA} throughout all year except during dry season that occurs in August (**Fig. 3**a). Winter and spring periods show similar trend of correlation, which corresponds with relationship for total time period. Periods G3 and G4 characterized with dry season and small number of observations show distinct pattern. Period G5 also shows weak correlation because of high flow oscillations in autumn. For hydrological analysis purposes relationship between discharges Q_{BILAJ} and Q_{JADOVA} is strong enough for periods in which inflow encourages energy production. On the other hand, correlation between discharge Q_{BILAJ} and $Q_{NOVČICA}$ shows no significant relationship (**Fig. 3**b). Two winter periods (G1 and G6) show same relationship pattern which corresponds with relationship for total time period. During spring period G2 relationship between Q_{BILAJ} and $Q_{NOVČICA}$ shows similar pattern for most of the data, with only extreme discharges deviating from this pattern. Periods G3, G4 and G5 show distinct pattern, because of the same reasons already determined for afore-mentioned Jadova River. There is visible significant dispersion on scatterplot Q_{BILAJ} and $Q_{NOVČICA}$ for discharges under 50 m^3/s (**Fig. 3**b), which is very important for determination of tailwater level and energy output.

Beside discharges, water surface elevation must be known on downstream profile of defined river reach in order to establish resulting water surface profile for given hydrological conditions. Downstream profile of defined river reach is GS Budak on Lika River (**Fig. 1**), and measured pairs of *Q-H* data for this profile are given on figure below (**Fig. 4**) for period from 2004.

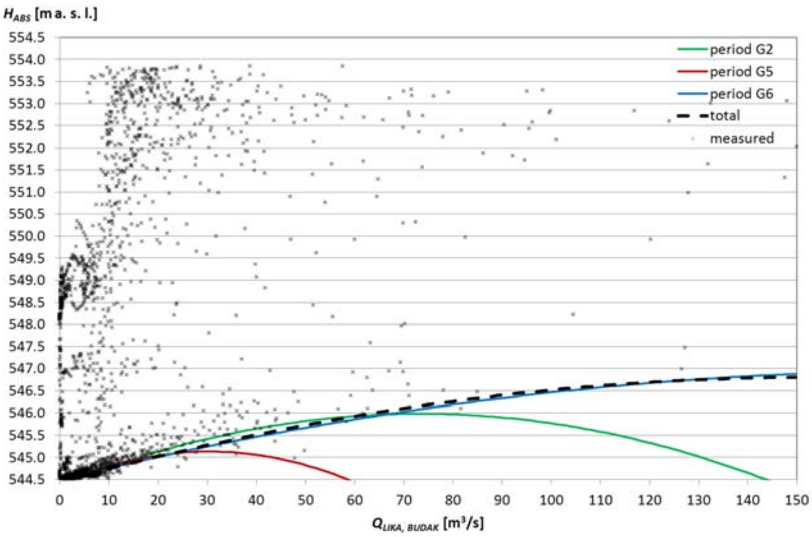

Fig. 4 Pairs of *Q-H* data for GS Budak.

From scatter plot of GS Budak (**Fig. 4**) is visible that its water levels are under influence of backwater flow from Kruščica reservoir. On figure is shown idealized discharge curve without backwater effect (**Fig. 4**, hidden line) and discharge curves for periods that are not influenced by Kruščica's backwater (winter period G6, spring period G2 and autumn period G5). These periods without backwater effect coincide with ones defined to have strong relationship between tributary discharge and Q_{BILAJ} (**Fig. 3**a, **Fig. 3**b). On following figure (**Fig. 5**) is shown hydrograph during year 2004 for Q_{SHPP} and absolute difference in water levels of two boundary condition profiles of defined river reach: GS Bilaj (upstream, **Fig. 1**) and GS Budak (downstream, **Fig. 1**).

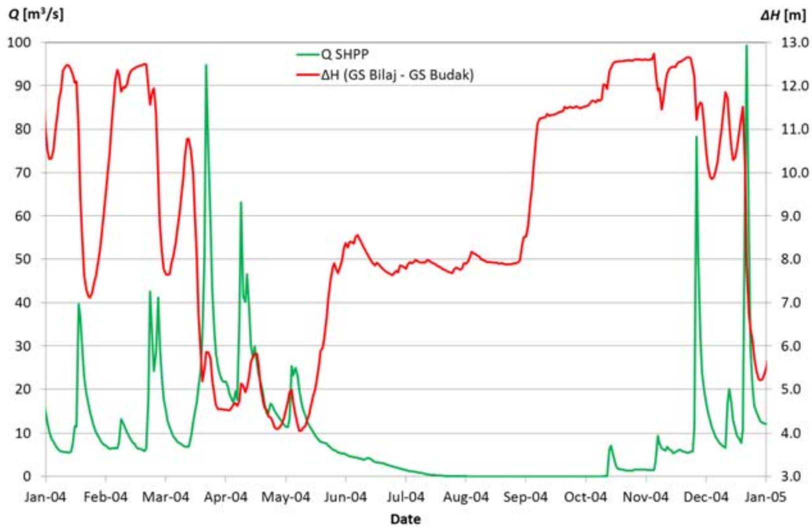

Fig. 5 Hydrograph for Q_{SHPP} and absolute difference in water levels on model boundary conditions in year 2004.

Hydrograph shows that during spring (period G2) when there is abundant inflow upstream backwater from reservoir Kruščica lowers available water head for energy production. During winter (periods G1 and G6) when there is reasonable inflow backwater influence oscillates and highest backwater effect coincides with peak discharges (**Fig. 5**). Period with most head available is during June through November (periods G3, G4 and G5) which is drought season. Backwater effect can cause increase in water elevation up to 10 m (**Fig. 4**). In such stochastic hydrological conditions there is no exact method to determine "stationary" hydrological boundary conditions for numerical modelling of flow through defined river reach. Therefore, characteristic values of discharge and water surface elevation cannot be used as reliable for numerical modelling of water surface profile and determination of tailwater at SHPP site.

4 RESULTS OF NUMERICAL MODELLING

Defined river reach is characterized with numerous submerged weirs which disturb flow field locally, creating pools and chutes. Calibration of roughness coefficient of such riverbed is usually impossible because weirs create local backwater effect which disturbs gravitational flow. Therefore, more emphasis must be given on calibration of coefficient of flow over weir crest and higher discharges which are less influenced by weirs than lower ones.

Because no deterministic pairs of *Q-H* points can be established on downstream boundary condition, standard procedure for energy production calculation cannot be used. Therefore, instead of using discrete values from discharge duration curve, all of the data from long-term observations must be used. Duration of period for which production is calculated must be long enough to include extremes with higher return period. For this analysis time period selected ranges from 2003 until 2011, with 2556 simulated daily hydrological events. Maximum discharges in this period are $Q_{max,\ Lika}$ = 145 m^3/s, $Q_{max,\ Jadova}$ = 103 m^3/s and $Q_{max,\ Novčica}$ = 105 m^3/s. When these values are compared with absolute extremes (Table 3), it shows that they reflect entire range of discharges that occur on this reach and that selected time period is reliable for calculation of tailwater elevation as input for energy output calculation. In this paper two variants of headwater elevations are defined: 555 m a. s. l. and 557 m a. s. l. Since energy production is not possible during restrictive hydrological conditions, *e.g.* during drought period or during very high backwater flow, not all given data can be included in calculation. Therefore, calculated pairs of SHPP tailwater data were filtered out to exclude ones that cannot be used. Filtered data included discharges 2 m^3/s < Q < 22 m^3/s and available head ΔH > 2 m (visible on **Fig. 6**).

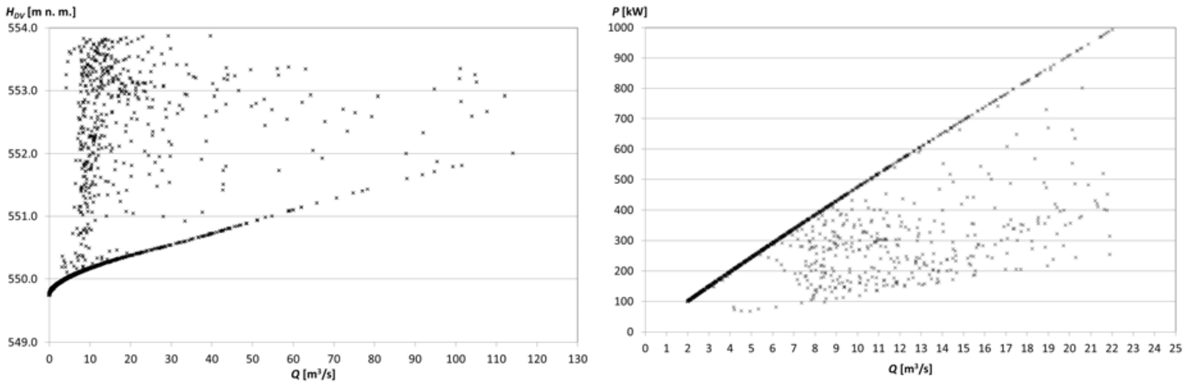

Fig. 6 Numerical model results: a) discharge - tailwater for SHPP profile; b) discharge - power

On next figure (**Fig. 7**) is given comparison of power duration curves for two defined headwater elevations.

$\overline{W_{yr}^{555}} = 1{,}90\ GWh$ $\overline{W_{yr}^{557}} = 2{,}80\ GWh$

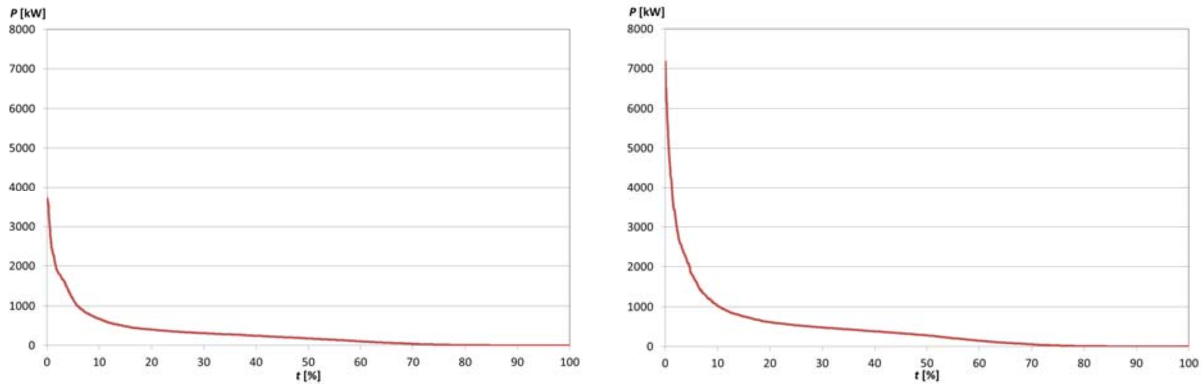

Fig. 7 Power duration curve for headwater elevation at: a) 555 m a. s. l.; b) 557 m a. s. l.

5 CONCLUSION

This paper presented overview of complex hydrological regime on Lika River. Established relationships between discharge of Lika River and its tributaries Jadova and Novčica enabled determination of boundary conditions for 1D numerical model. Numerical modelling of flow was used for description of hydrological regime and determination of energy output for SHPP which showed that potential for energy harvesting of small watercourses at far end of hydro power plant reservoirs exists.

References

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