ASSESSMENT OF CLIMATE CHANGE IMPACT ON FLOOD FLOWS IN TWO CATCHMENTS IN SERBIA

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Summary *Hydraulic structures are designed according to flows of a given return period. The design flows, estimated by means of statistical analysis, depend on the observations, while climate change impact is not explicitly taken into account. As operating life of most hydraulic structures spreads over several decades, climate change impact should not be neglected.*

In this paper an analysis of climate change impact on flood flows is conducted for the Kolubara River at Slovac and for the Toplica River at Doljevac. The analysis is performed on the outputs of hydrologic modelling with the precipitation and temperature projections as the input. The Peaks over Threshold (POT) method is applied for frequency analysis of floods extracted from the flow projections. Characteristic quantiles are calculated for two future periods and compared to those estimated over the baseline period. The results suggest an increase in flood flows, particularly in the mid-21st century. Regardless of considerable uncertainty, these results can be used as indication of increase in design flows, and should be therefore taken into consideration within the hydraulic structure design.

Key words: *climate change, flood flows, POT method, the HBV-light model, the Kolubara River, the Toplica River*

1. INTRODUCTION

An accurate estimation of flood flows of given return period is crucial for design and exploitation of hydraulic structures. The design flows are commonly estimated from the observed flows by employing either the annual maxima method (AM) or the Peak over Threshold (POT) method (e.g. Vukmirović, 1991; Vukmirović and Petrović, 1997; Osuch

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et al., 2016). Both methods rely on the observations, whereas the climate change due to an increase in greenhouse gases (GHG) concentration cannot be explicitly accounted for. As the operating life of many hydraulic structures range over couple of decades, climate change impact due to increase in GHG concentrations should not be disregarded. In other words, it has to be assessed whether climate change may lead to an increase in design flows to preserve a safety margin.

Such an analysis should be based on the flow projections, which are obtained from the climate ones, and a calibrated hydrological model (e.g. Wilby, 2005; Prudhomme and Davies, 2009a). Climate projections are made by using General Circulation Models (GCM), which are run under an assumed GHG emission scenario. The GCM results have to be downscaled to be suitable for hydrological modelling, and bias-corrected to be consistent with the monthly distributions of the observed precipitation and temperature distributions in the baseline period (e.g. Xu, 1999; Teutschbein and Seibert, 2012; Refsgaard et al., 2014). For GCM output downscaling either statistical method or dynamical methods (i.e. Regional Climate Models – RCM) can be employed (e.g. Bae et al., 2011). The climate projections are used as an input to a calibrated hydrological model, resulting in flow projections, i.e. (daily) flow series in a future period. The impact of climate change is assessed by comparing characteristic flows (e.g. mean flows, flow percentiles) calculated for the future to the corresponding values estimated for the baseline period (e.g. Kay et al., 2009; Pechlivanidis et al., 2016). When it comes to flood flows, percentiles (e.g. 90th or 95th), high-flow segment of a flow duration curve or high-flow quantiles are commonly analysed (e.g. Osuch et al., 2016; Hoang et al., 2016). Precipitation and temperature simulated by climate models and corrected for bias correspond to the observed series in terms of statistical distributions rather than in terms of time series. The distributions of the observed and simulated climate usually have good agreement for the moderate values, but can significantly differ at tails. Consequently, the same is true for hydrologic series simulated with the climate model outputs (e.g. Vaze et al., 2011; Todorovic and Plavsic, 2015). This can lead to considerable differences between the annual maxima (AM) series of the observed and simulated flows.

In this paper, we investigate whether the POT method could be used in the climate change impact studies as the flood flows are not selected according to the occurrence year, but rather according to their magnitude (Todorović and Yevjevich, 1969; Plavšić, 2005; Kay et al., 2009). Flood flows are estimated from the flow projections for the near future and mid-21st century, followed by the POT method application. Impact of climate change is assessed by comparing peak flow statistics and the quantiles obtained for the future to the baseline period. The analysis is carried out for two catchments in Serbia.

2. METHODOLOGY

2.1 CATCHMENTS AND DATA

Flow projections are made for two catchments in Serbia, namely the Kolubara River upstream of the Slovac stream gauge, and the Toplica River upstream of the Doljevac stream gauge. In both catchments agricultural land and forests prevail, and the observed flows are not affected by river training measures (Todorović and Plavšić, 2015). Catchment properties and gauging stations are listed in Table 1. Both catchments are characterised by pronounced seasonality in flows: namely, flood flows are usually observed in early spring (due to snowmelt), though they may also occur in summer due to intensive convective storms, particularly in the Kolubara River basin.

Table 1. Catchments and meteorological stations

River	Stream Gauge	Draining Area [km^2]	Mean Flow [m^3/s]	Meteorological Stations	Available Record Period
Kolubara	Slovac	995	9.8	Valjevo	1954-2013
Toplica	Doljevac	2052	8.77	Kopaonik, Kursumlija, Nis, Prokuplje	1980-2013

2.2 HYDROLOGIC PROJECTIONS UNDER CLIMATE CHANGE

Flood flows are selected from the daily flow projections, which were obtained for the Slovac on the Kolubara River and the Doljevac on the Toplica River. Climate change impact on hydrologic regime in these catchments is elaborated by Todorović and Plavšić (2015), and it is briefly outlined here.

Daily flows by the end of the 21st century are simulated with the HBV-light hydrologic model (Seibert and Vis, 2012), which was forced with a climate projections. The climate projections are made with the ECHAM5-EBU-POM climate modelling chain (Djurdjevic and Rajkovic, 2010), which was run under A1B and A2 emission scenarios (IPCC, 2000). The outputs of the GCM-RCM chain are bias-corrected to fit the distributions of the monthly observations at the considered meteorological stations (Table) in the baseline period (1961-1990).

The semi-lumped HBV-light model (version with three linear reservoirs) was calibrated over the baseline period for the Kolubara River, and in 1981-2000 for the Toplica River, and evaluated in the remainder of the record period. Semi-lumped model means that the entire catchment is represented by a single parameter set, but the meteorological forcing is adjusted to account for changes with elevation. The model is calibrated according to a composite objective function that reflects model performance in high- (Nash-Sutcliffe coefficient, *NSE*) and low-flow domain (*NSE* for log-transformed flows), and model ability to reproduce flow volume (volumetric efficiency *VE*; Criss & Winston, 2008). The objectives' weights are slightly perturbed resulting in the 10-member ensemble, which combined with two GHG emission scenarios yields 20 flow projections.

2.3 ANALYSIS OF CLIMATE CHANGE IMPACT ON FLOOD FLOWS

The flow projections in the near future (2015-2040) and in mid-21st century (2040-2070) are used to extract peaks over selected thresholds according to the minimum time elapsed from the previous peak flow, and minimum flow that should occur in-between two consecutive events (defined as a ratio to the peak flow). It is assumed that meeting these criteria warrants independent flow peaks (e.g. Plavšić, 2005; Willems, 2009). In this paper, minimum lapse time is set to 15 days and minimum flow in-between events is set to 30% of the peak flow (these parameters are common to both catchments). The thresholds of 50 m^3/s for the Kolubara River and 70 m^3/s for the Toplica River are selected to provide one exceedance per year on average for all considered periods. Although Kay et al. (2009) recommended threshold value that results in three exceedance per year on average, the goal of this research is to consider extremely high flows so higher thresholds are set.

The distribution of flood maxima in the POT method is calculated by combining distribution of peak occurrences (represented by a discrete distribution), and distribution of peak magnitudes (described by a continuous distribution) (Plavšić, 2005). The discrete distribution is selected according to the dispersion index I_d, which is a ratio between the variance and mean value of a series of annual number of peaks. If I_d takes value between 0.8 and 1.2, the Poisson distribution should be selected; smaller values of I_d indicate the binomial distribution, while values greater than 1.2 suggest the negative binomial distribution (Vukmirović, 1990; Vukmirović and Petrović, 1997; Plavšić, 2005). Peak magnitudes are commonly described by the exponential, Weibull or generalised Pareto distributions, although application of other distributions has been reported (for a review see Plavšić, 2005).

In this paper flow quantiles are calculated by applying a combination of the Poisson and Exponential distributions (P+E model):

$$x = x_B + \alpha\left[-\ln\left(-\frac{\ln F}{\lambda}\right)\right] \tag{1}$$

where x denotes flow quantile, x_B is the threshold, F is the non-exceedance probability, α and λ are parameters of the Exponential and Poisson distributions, respectively. The parameters can be estimated with the method of moments (Kottegoda and Rosso, 2008):

$$\alpha = \bar{z} \tag{2}$$

$$\lambda = \bar{n} \tag{3}$$

where $\bar{z}$ stands for the mean peak magnitude, and $\bar{n}$ denotes mean annual number of peaks, and it is a ratio between the number of peaks and length of the period.

In this paper, impact of climate change on flood flows is estimated by comparing (1) mean annual number of peaks, (2) mean peak magnitude, and (3) flow quantiles calculated from simulated flows (hydrologic model forced with the outputs of the climate model) for the future and baseline periods. Flows of following characteristic return periods are estimated: 2-, 5-, 10-, 20-, 50-, 100-, 200-, 500-, and 1000-year.

The P+E model is selected primarily because of its parsimony and simplicity (i.e. model parameters can be easily estimated). Application of the Poisson distribution is also justified by values of I_d index. Uncertainties due to statistical estimation in the modelling chain are assumed negligible compared to uncertainty stemming from other elements (GHG emission scenarios, climate and hydrologic modelling), however, further research is required to approve this assumption.

3. RESULTS AND DISCUSSION

Empirical distributions of peaks in the baseline period (1961-1990) and in the mid-21st century (2015-2040) for the Kolubara River are shown in Figure 13. Comparison of empirical distributions of the observed and simulated peaks on top panel in Figure 13 indicates that flood flows are underestimated by the modelling chains. Therefore, the changes in flood flows are estimated from the simulated flows only. The results also indicate considerable uncertainty in flood flow projections, which increases with the return period and lag from the baseline period.

Mean annual number of peaks and mean peak magnitude for three time slices are shown in

Figure2. The results vary with the catchment, and can be summarised as follows:

- The Kolubara River:
    - Increase in number of peak occurrences (top panel in
    - Figure2) can be expected in the second time slice (2040-2070), while this number is expected to remain relatively unchanged in the near future.
    - Peak magnitudes (bottom panel in
    - Figure2) depend on the emission scenario: the A1B scenario suggests decrease, while the A2 scenario indicates unchanged peak magnitudes in 2015-2040, and increase in 2040-2070 (also shown in Figure 13).
- The Toplica River:
    - The results for the Toplica River are more sensitive to the emission scenario, i.e. two scenarios result in opposite signs of the change in annual number of peaks: namely, the A2 scenario suggests increase in annual number of peaks, especially in the near future, while A1B indicates decrease.
    - Similar trends are obtained for peak magnitudes, i.e. the A2 scenario indicates that severe floods in the future (increase in both peak frequency and magnitude).

Relative changes in estimated flow quantiles are presented in Figure 3. The results show decrease in all quantiles for the Kolubara River in the near future, and increase in the distant future. Changes in the quantiles for the Toplica River are very uncertain (indicated by larger width of the boxplots), but the results generally show that increase in extreme floods may be expected.

Uncertainty in the flood projections is high, which is indicated by great variation in the results. Therefore, flood flow quantiles obtained for a future period cannot be used immediately for hydraulic structure design: namely, quantiles estimated from observed and simulated flows differ markedly (illustrated on top panel in Figure *13*1). However, the analysis presented should be carried out to examine for presence of tendency in flood flows due to increase in GHG concentration. If the projections unequivocally indicate increase in design flows within the structure operating life (i.e. there is no variation in sign of change across the ensemble), it may well indicate higher probability of exceedance of the design flow in the future, and thus higher risk. Therefore, this indication should be indirectly included in a structure design to preserve a safety margin.

4. CONCLUSIONS

In this paper, climate change impact on flood flows in two catchments in Serbia is estimated by applying the POT method. The series of peaks are extracted from an ensemble of 10 hydrologic simulations with different parameter sets under two emission scenarios. Changes in annual number of peaks, peak magnitude and flood flow quantiles in two future periods relative to the baseline period are calculated. The results generally suggest a decrease in flood flows in the near future, and increase in the distant future for the Kolubara River, and increase of flood flows for the Toplica River. However, the results vary with both assumed emission scenario and hydrologic model parameter sets.

As operating life of many hydraulic structures is expected to cover several decades, impact of climate change should be taken into account. On the other hand, flow projections under climate change imply considerable uncertainties, particularly in terms of extreme flows. Therefore, estimated quantiles for a future period cannot be immediately used for a structure design. However, relative comparison between the flood flows in a future and the baseline period can suggest whether increase in design flows due to climate change may be expected. If there is no uncertainty regarding the sign of change, i.e. if all ensemble members indicate increase in design flows, it is recommended to include this indication in the design process (for example, to design a structure according to the upper limit of the confidence interval of a flood quantile).

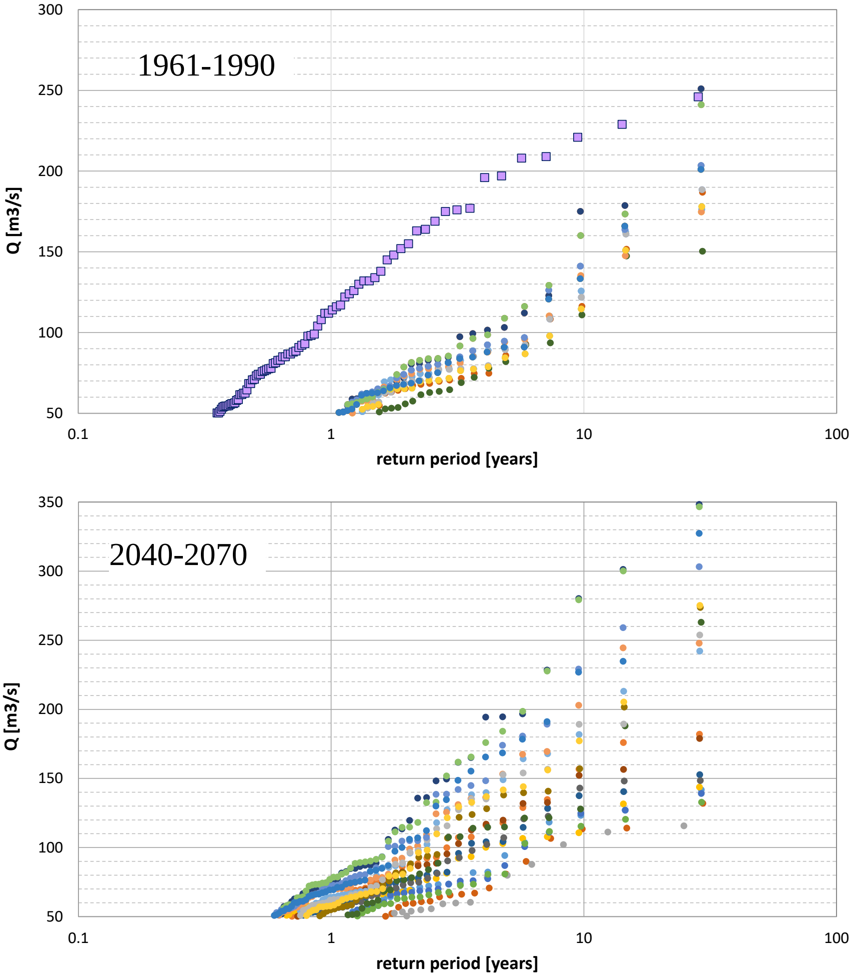

Figure 1. Empirical distributions of peaks over threshold from 20 simulations at the Kolubara River in the baseline period (top) and in the future (bottom panel). Squares in

the top panel denote observed flows.

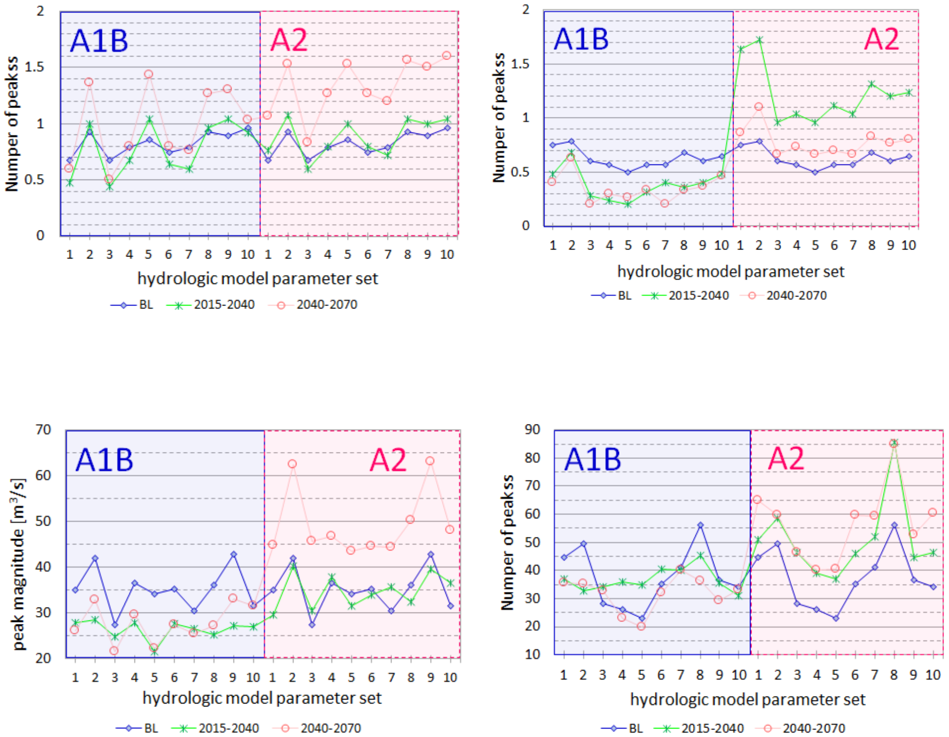

Figure 2. Mean annual number of peaks (top) and peak magnitudes (bottom panels) for each hydrologic simulation: the Kolubara River (left) and the Toplica River (right panels)

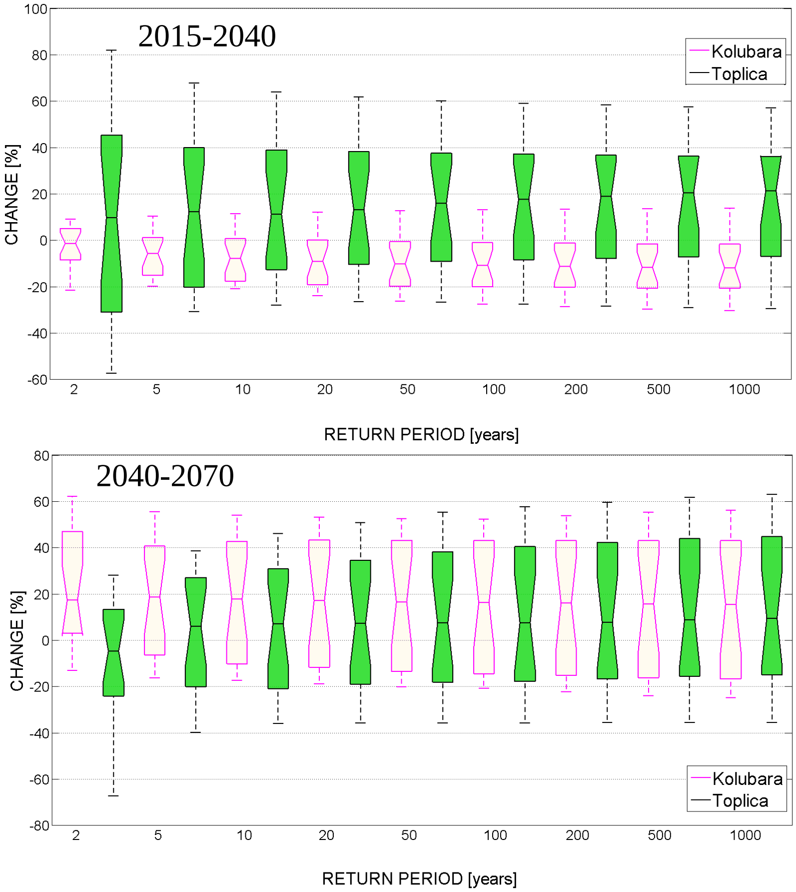

Figure 3. Climate change impact on flood flow quantiles: near future (top) and mid-21st century (bottom panel).

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УТИЦАЈ КЛИМАТСКИХ ПРОМЕНА НА ВЕЛИКЕ ВОДЕ НА ДВА СЛИВА У СРБИЈИ

Резиме: *Хидротехнички објекти се димензионишу према протоцима великих вода изабраног повратног периода. Оцењени квантили зависе од осмотреног низа, док се ефекат климатских промена не укључује експлицитно у прорачун. Како је животни век већине хидротехничких грађевина неколико деценија, утицај климатских промена не би требало занемарити.*

У овом раду анализиран је утицај климатских промена на велике воде на реци Колубари (в.с. Словац) и на реци Топлици (в.с. Дољевац). Анализа је урађена на основу резултата хидролошког модела, при чему су улазни метеоролошки подаци (падавине и температуре) добијени из климатских пројекција. За оцену квантила велихих вода из добијених хидролошких пројекција примењена је метода метода прекорачења изнад прага (метода пикова). Квантили неколико карактеристичних повратних периода су срачунати за два будућа периода и упоређени са квантилима одређеним за референтни период. Резултати указују на повећање меродавних протока, посебно средином 21. века. Без обзира на велике неодређености, резултати овакве анализе се могу користити као индикатор повећања меродавних протока који би требало укључити у димензионисање хидротехничких објеката.

Кључне речи: *Климатске промене, велике воде, метода прекорачења изнад прага (POT метода), HBV-light модел, река Колубара, река Топлица*