LONGITUDINAL ASSESSMENT OF HYDROPEAKING IMPACTS AND EVALUATION OF MITIGATION MEASURES

FRANZ GREIMEL
Institute of Hydrobiology and Aquatic Ecosystem Management, BOKU University, Vienna, Austria

BERNHARD ZEIRINGER
Institute of Hydrobiology and Aquatic Ecosystem Management, BOKU University, Vienna, Austria

CHRISTOPH HAUER
Institute of Water Management, Hydrology and Hydraulic Engineering, BOKU University, Vienna, Austria

PATRICK HOLZAPFEL
Institute of Water Management, Hydrology and Hydraulic Engineering, BOKU University, Vienna, Austria

MARTIN FUHRMANN
Institute of Water Management, Hydrology and Hydraulic Engineering, BOKU University, Vienna, Austria

STEFAN SCHMUTZ
Institute of Hydrobiology and Aquatic Ecosystem Management, BOKU University, Vienna, Austria

Hydropeaking is one of the main environmental impacts on running water ecosystems in Austria. Many affected rivers have a poor ecological status. Habitats for fish and invertebrates can be reduced, abundances can be diminished and organisms are affected by drift and stranding during the increase and decrease phases of peaks. To assess the ecological impact of hydro peaking, intensity thresholds according to different species and life stages can be applied. However, due to retention effects, the hydrological impact is not constant in a longitudinal view. A model to assess hydrological impacts considering distances to the power plant outlets is needed. For this purpose, we developed a model by detecting fluctuation intensities out of multiple hydrographs along the affected river reaches. This forms the basis for describing potential effects of hydro peaking by contrasting the varying hydrological impact intensity to threshold values of river organisms. Furthermore, mitigation scenarios can be evaluated, both ecologically and economically, by modelling modified hydro peaking intensities.

1 INTRODUCTION

Hydropeaking is one of the chief environmental impacts on running water ecosystems in Austria. About 800 km (mainly in the grayling zone) are affected by hydropeaking due to hydropower production [1]. These rivers have experienced severe flow alteration due to human activities and are characterized by dynamic perturbations in their hydrographs. Many affected rivers have a poor ecological status as flow is a major driver for physical habitat in streams and a major determinant of biotic composition. Habitats for fish and invertebrates can be reduced, abundances can be diminished and organisms are affected by drift and stranding during the increase and decrease phases of peaks. One way of assessing the ecological impact of hydropeaking, is to apply intensity thresholds according to different species and life stages [2]. A detailed longitudinal assessment requires taking into consideration the river morphology of the investigated river reach, as most existing intensity thresholds refer to water level changes (in opposition to flow changes). Furthermore, habitat availability plays a major role. However, the predominant hydrological situation at hydro peaked rivers (intensity, frequency and timing of flow fluctuations) is the cause of hydro peaking impacts and therefore the basis for further analysis. In this study we focus exclusively on modelling the hydrological situation in a longitudinal view.

2 STUDY AREA

The study area is confined to a river reach of the Ziller river in the Austrian alpine region. This river is located in the grayling zone within the Ecoregion Alps (Figure 1). The length of the investigated river section is about 10 km starting at the power plant outlet with a mean flow of 30 m³/s and a catchment size of about 650 km². The majority of the catchment is affected by the high-head storage hydropower plant Mayrhofen, with a maximum turbine capacity of 90 m³/s. More than 5 flow fluctuations a day occur frequently due to the power plant operation mode, which can be observed at 2 hydrographs provided by the Austrian Hydrographic Service (data resolution 15 minutes); the river stretch between the gauges is 6.5 km.

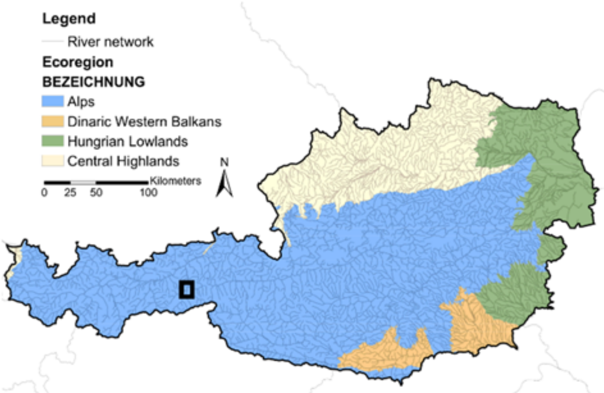

Figure 1. Spatial location of the investigated river reach (box).

3 STUDY DESIGN

Flow conditions in hydro peaked rivers are highly complex and difficult to grasp. Tools to characterize and contrast sub-daily flow fluctuations using discrete hydrograph curves allow to describe the hydrological conditions at the measuring points [3,4]: Continuous time steps (ts) with equal flow trend are defined as an event. Increase and decrease events can be detected separately and are described by a set of intensity parameters (Table 1 – parameter 1-5). Furthermore, specific events can be selected according to event intensities or timing.

Table 1. Event based flow fluctuation parameters – definitions and units [3].

Nr.	Parameter	Acronym	Definition	Unit
1	Maximum flow fluctuation rate	MAFR	$\max(\mathrm{abs}((Q_{tsn+1}) - (Q_{tsn})))$	$(m^3/s)/ts$
2	Mean flow fluctuation rate	MEFR	Amplitude/Duration	$(m^3/s)/ts$
3	Amplitude	AMP	$Q_{max} - Q_{min}$	m^3/s
4	Flow ratio	FR	Q_{max}/Q_{min}	
5	Duration	DUR	$ts_e - ts_b$	ts
6	Daily number	CNT	Number of events per day	

ts_b - time step event beginning, ts_e - time step event ending, Q_{max} - maximum event flow, Q_{min} - minimum event flow, Q_{tsn} - flow of a specific time step, Q_{tsn+1} - flow of subsequent time step, max – maximum, abs – absolute.

A model to assess the hydrological impact, respectively the alteration of event intensities along the river reach requires analysis of multiple hydrographs. At the moment only data of the two permanent hydrographs are available; we used hydrograph data from the year 2008 (01.01-31.12). (To increase the assessment accuracy we additionally installed two temporal gauges. The data will be available in spring 2016 at the earliest. However, to illustrate the proposed method at this early stage, we use the present data in combination with information of the electricity company.)

To allow statistical analysis of changes between the hydrographs, as many associated events (AE) (events which can be identified at both of the neighbouring hydrographs – Figure 2) as possible need to be found. Therefore it is necessary that concordant data periods are available for both hydrographs, enabling an analysis of a period of one or multiple years. AE can be detected by the timing, the base flow conditions at the event beginning and the event amplitude, which have to be similar at both hydrographs. Therefore, a cross correlation analysis is applied to calculate the flow time between the hydrographs. AE are separated from events which cannot be found at the neighbouring hydrograph. The allocation of AE is validated by scatter plots for parameters which are not used to define AE.

Statistical analysis of AE allows a detailed description of the event changes between the hydrographs based on measured values, whereat all intensity parameters can be analysed. Furthermore, the analysis can be specified for specific base flow conditions as well as specific event parameter values. In consequence, the hydrological impact can be modelled in great detail by using multiple hydrographs.

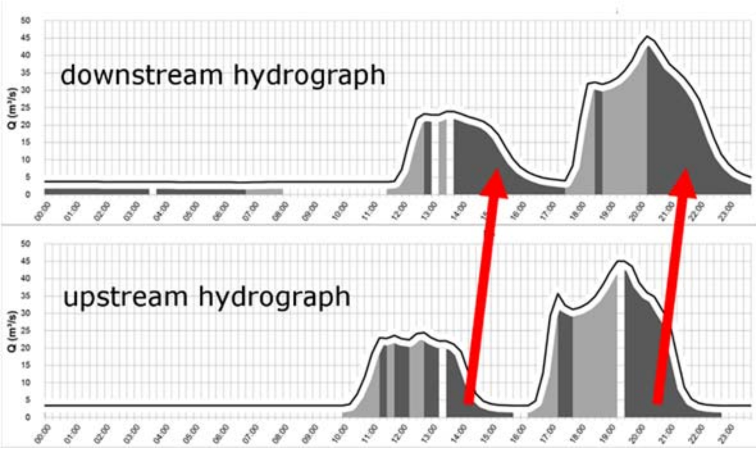

Figure 2. Associated decrease events (red arrows) (light grey: increase events; dark grey: decrease events)

4 RESULTS/INTERPRETATION

The parameter flow fluctuation rate of decrease events (ramping rate) is an important parameter to assess the stranding risk of fishes [2]. Therefore, we focus on the results for the parameter maximum flow fluctuation rate of decrease events in this study.

There were more than nine hundred associated events (AE) identified at the investigated hydrographs in the year 2008. For sufficient analysis a high quality of the associated event allocation is essential, which can be validated by scatterplots contrasting the parameter values of AE at the neighbouring hydrographs (Figure 3). As expected, a strong correlation exists between the hydrographs, which indicates that the majority of AE are assigned correctly. It can be assumed that deviations are linked to different base flow conditions, as retention effects vary in connection with different river bed roughness and water levels.

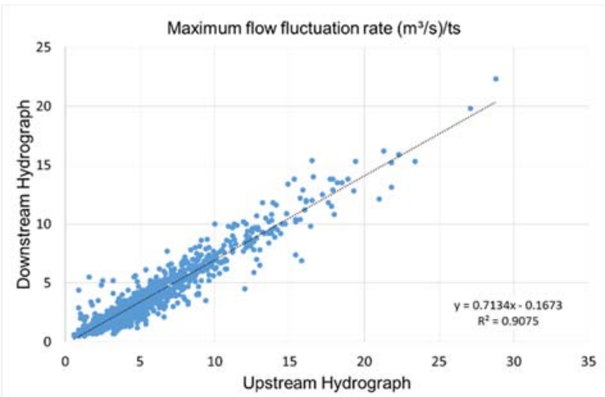

Figure 3. Validation of the associated event allocation (N=916) (example: parameter maximum flow fluctuation rate of decrease events).

As mentioned above, at present only data from the permanent hydrographs are available (Figure 4: circles at km 1.8 and 8.45). As a consequence, an accurate assessment of the hydrological impact is limited to the river stretch between the hydrographs at the moment. To model hydrological impacts starting at the power plant outlet, we installed two more gauges (Figure 4: cross at km 0.1 and 5.5) measuring a one year period - the data will be available in spring 2016. In the meantime, we use the information of the electricity company to illustrate the intention of the study. (Maximum down ramping rates of 90 m^3/s (turbine capacity) within 15 minutes are not unusual.)

Figure 4 illustrates the approximate retention effect regarding ramping rates of decrease events in a longitudinal view, considering all associated events of the year 2008. The continuous line equals the maximum flow fluctuation rate starting at the power plant outlet with 90 m³/s/ts, measured at the upstream gauge with 28.8 m³/s and at the downstream gauge with 22.3 m³/s/ts. The adjusted power function is based on these values. The dotted line is based on the median down ramping rates at the upstream hydrograph (4.7 m³/s/ts), at the downstream hydrograph (3.1 m³/s/ts) and the assumption of a power function, similar to the maximum flow fluctuation rate.

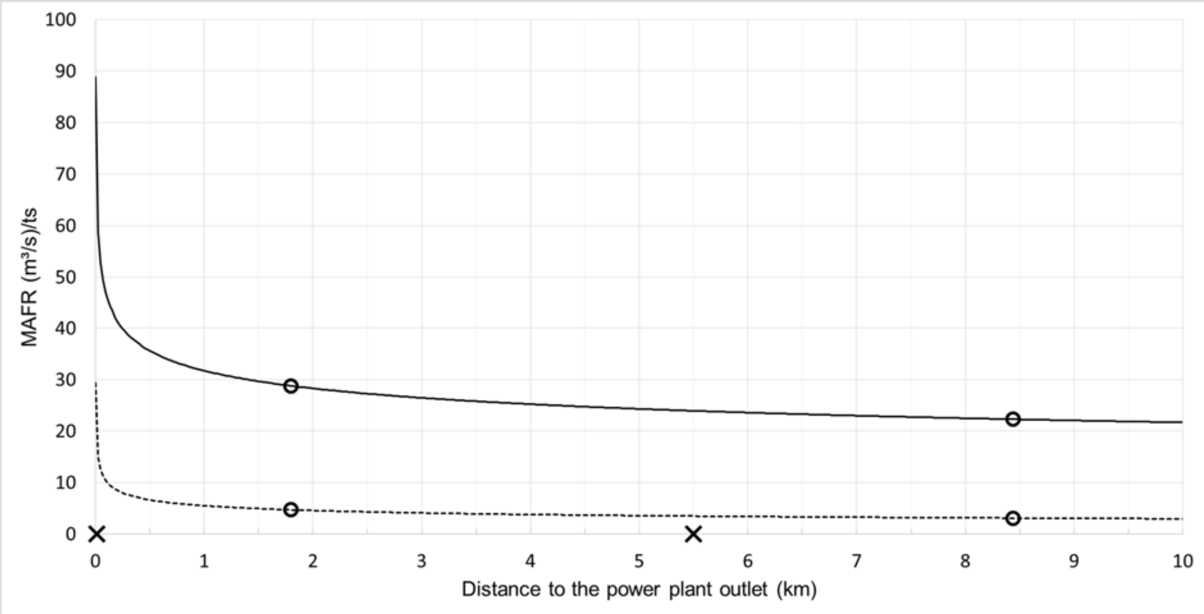

Figure 4. Hydrological impact regarding the parameter maximum flow fluctuation rate of decrease events (continuous line: annual maximum; dotted line: annual median; circles: present hydrograph data; cross: future hydrograph data).

The ramping rates show a very strong decreasing trend next to the turbine. The retention effects are less pronounced at distances over circa 2 km downstream of the turbines. The decreasing trend becomes very slight in the section between the hydrographs. This analysis can be applied using all intensity parameters (Table 1 – parameter 1-5) and curves can be calculated for the maximum and median event intensity as well as for any other intensity (percentiles), which allows to describe intensities, frequencies and timing of events in a longitudinal view by interpolating between the gauges. Furthermore, base flow conditions can be considered to analyze the retention effects, adapted to predominant flow conditions (low medium and high flow). In summary, the hydrological impact can be assessed in a longitudinal view; the accuracy depends on the number of gauges in the investigated river stretch. This offers a wide range of applications: The calculated intensities and frequencies can be used as input parameters for hydraulic modelling and/or hydraulic models can be validated. The hydrologic impact can be assessed in great detail at biological monitoring stretches, which is the basis for a detailed investigation of ecological effects. The operation mode of a power plant could be adjusted to the present flow situation, the determined retention effects and the vulnerability of river organisms in order to minimize ecological impacts and economical losses. Furthermore, the proposed method can be used to contrast economic losses to ecological benefits of specific mitigation scenarios.

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