HYDROPEAKING DIFFUSION ACTIVITIES IN ALPINE RIVERS

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Water temperature strongly dominates biological communities and ecological processes, and temperature is sensitive to climatic conditions and human activities such as hydropower regulation. Especially in the most vulnerable mountainous area of Alpine rivers, intermittent hydropower operation results in strong "thermalpeaking" effects downstream often associated with the intermittent "hydropeaking" phenomenon. Temporal and spatial variations of the peaking processes are examined in this work through the application of four indicators of sub-daily hydrological and thermal variability to selected watersheds in the Alpine region. River water temperature diffusion behaviors in 7 major gauging stations are analyzed at the catchment scale and over the last three decades. The results reveal relevant temporal and spatial scales of the hydro- and thermo-peaking variations, and suggest a broader view on their potential ecological implications.

1 INTRODUCTION

As a consequence of hydroelectric development and an extension of geomorphological variation, catchment hydrological and thermal regimes will be altered significantly along the rivers. A period of higher discharge dynamics of hydropeaking (HP) will be followed by an interrupted thermalpeaking (TP) effect with less harsh and moderate environmental conditions. The dimensions of change in the riverine environment strongly depend on river size, discharge and flow dynamics as well as the water-source contributions. Substantial changes on the water and thermal regimes of hydropower-affected catchments are processes that will take place both on the global scale and on regional scale [1]. River systems in the alpine environments are with typical features of the landscape, receiving and distributing water, solid substances, nutrients and other materials. Little is known about the relationships between catchment characteristics, flow regime diversity and hydropower influence on the downstream rivers [2].

In this paper we focused on the characteristics of sub-daily river water hydropeaking variability of the middle Rhone River Basin, Switzerland. A longitudinal diffusion model of the "peaking effects" characterization based on the mass and momentum conservation theory can feature the impacts from the HPP activities on rivers with more detailed understanding from the aspects of river morphology. The analysis could provide more insights into water quality management and habitat suitability for hydropower affected rivers.

2 METHODS

2.1 One dimensional advection-diffusion model

Under the background that the river section in an open channel flow with longitudinal slope s is receiving hypolimnion water release from a hydropower plant, 1-dimensional hydro- and thermo-advection-diffusion model is developed for the propagation of these two peaking waves. In the absence of lateral inflows, the simplified equation is applied according to the hydrologic dynamics and heat transport equation of energy budget under the hypothesis of non-uniform and unsteady flow conditions (Eq. 1 and 2). Boundary conditions are the known hydrological, river water temperature and geometric parameters at the upstream and downstream stations, respectively.

$$\frac{\partial D}{\partial t} + c\frac{\partial D}{\partial x} = k_w \frac{\partial^2 D}{\partial x^2} \quad (1)$$

where c is the celerity of hydrodynamic wave; k_w is hydrodynamic diffusion coefficient which $k_w = \frac{Q}{2Bj}$; friction term $j = \frac{U^2}{k_\chi^2 R_h^\chi}$; and hydraulics radius $R_h = \frac{A}{P}$;

The heat transport equation of energy budget is written in the same fashion Eq. (1), but T is substituted for D, and the coefficient of heat diffusivity is used in the place of molecular diffusivity k_t.

$$\frac{\partial \theta}{\partial t} + U\frac{\partial \theta}{\partial x} = k_t \frac{\partial^2 \theta}{\partial x^2} - r\theta - f\cos(\omega t) \quad (2)$$

where f is the scale of daily natural exchange of temperature; r is the effects of convective heat transfer with air. Simplified analytical solution for the hydrodynamic and thermal-dynamic equation is developed by (Toffolon, 2010).

The key parameters: the hydrodynamic diffusion coefficient k_w for hydrodynamic square waves; and coefficient of thermal diffusivity [3] are determined by Eq. (3) and Eq. (4). Thus, the cross-section width, slope and the Manning's roughness coefficient are detected as the most direct and important geomorphologic parameters in determining the hydro and thermal diffusivity coefficient.

$$k_w = \frac{Q{k_\chi}^2}{2BU^2} \quad (3)$$

$$k_t = \frac{5.86 * n * U * D}{\left(A/P\right)^{1/6}} \quad (4)$$

where Q is water discharge; k_χ is the Gauckler-Sticker coefficient; B is the river width; U is cross-section averaged velocity; n is manning's roughness coefficient; D is water depth; A is cross-section area; P is wetted premier.

Understanding the time and distance where the hydropeaking and thermopeaking waves begin to decay due to dramatic decrease in depth is important for the diffusion and attenuation behaviors of the river is crucial more than just the analytical solution of the equations. Estimations for The characteristic distance of the hydrodynamic and thermodynamic waves (denoted as X_{-wDeca} and X_{-tDeca}, respectively) where the water depth or water temperature reached half the equilibrium amount of the initial condition are calculated using Eq. (5) and (6).

$$X_{-tDeca} = \frac{(\theta_0 Q_0 + \theta_u Q)T_{hp}}{(\theta_0 + \Delta\theta)B2D_0} \quad (5)$$

$$X_{-wDeca} = \frac{Q_p T_{hp}}{BD_p} \quad (6)$$

in which Q_0 and D_0 is the base flow discharge and flow depth; ΔD is the difference between Peak depth D_p and D_0; Similarly, θ_u is the base flow temperature; $\Delta\theta$ is the difference of temperature changes; T_{hp} is the release duration.

2.2 Defining analytical units and model scale

To understand the longitudinal distribution of the peak discharge/temperature in the main stream, we cannot ignore the contributions from tributaries. The Drainage-Area-Ratio Method [4] is applied for all the main sub-tributaries of each junction point using the known total discharge. Relative change of the sub-tributary inflow contribution is calculated by Eq. (7).

$$DQ_i = \text{abs}(Q_i - \bar{Q}_{i-1}) - Q_{i-1_{75}}, \forall\ (i = 1, \dots, n-1;\ \bar{Q}_{i-1} \neq 0) \quad (7)$$

in which DQ_i is the relative change indicator for Q_i; $\bar{Q}_{i-1}$ and $Q_{i-1_{75}}$ is the mean and 75th percentile of the multi-year daily average river water temperature at the closest upstream junction point i-1, respectively. DQ_i greater than 0 means the sub-tributary inflow is not negligible and the analytical unit (longitudinal length of studied river reach) stops above its junction point accordingly.

Apart from the sub-tributary inflows, physical obstructions such as hydropower dams, major impoundments, lakes or other geomorphological obstructions, which could possibly interrupt the river connectivity, should be recognized and separated from the homogeneous river reach as analytical unit(s). Given the specific conditions of the Alpine Rivers with major snow melt effects in spring and complicated heatwaves effects from air temperature or flooding that frequently occurr in summer, the model is more focused on hydropeaking during the winter season (Jan and Feb). Spatial resolutions are 10 m and the time step is one hour.

3 STUDY AREA AND DATABASE

The selected initial upstream gauging station (2346) of the The Rhone River Basin is located at Brig Glis, the Middle Rhone River watershed, with storage hydropower station running in the upstream (100 m). The stretch of river downstream to the gauging station (2011) at Sion is taken as the study river reach (Figure 1). Considering the geomorphology obstructions (e.g. weirs, dams, lakes) and significant discharge contribution by the sub-tributaries (evaluated according to part 2.2), the mainstream of the studied river reach was divided into four major subsections. Geomorphology parameters of the riverbed are illustrated in Table 1.

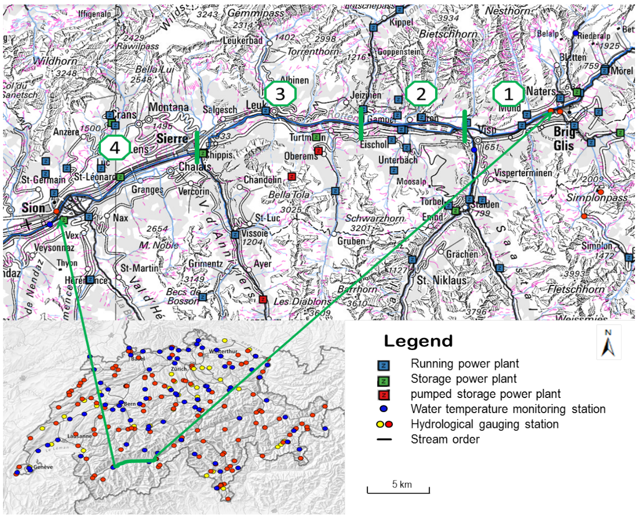

Figure 1. Rhone river basin in Switzerland and the highlighted study area (upstream on the right and downstream on the left) river networks. Small green bars and circled numbers (1-4) are sub-reaches calculated individually in this paper.

Table 1. Geomorphology input data for the study case of the four river sections.

Junction point	Name	Distance (km)	Elevation m a.s.l	surface area of catchment (km^2)	Channel slope *s*	River width (m)	Manning's coeffiient
0 (2346)	Rhone-Brig	0.00	667	70.00	0.0029	30	0.015
1	Rhone-Visp	18.40	659	182.82	0.005	35	0.025
2	Rhone-Gamnel	35.62	630	438.13	0.003	70	0.012
3	Rhone-Sierre	54.70	524	588.09	0.005	50	0.025
4 (2011)	Rhône-Sion	76.01	495	550.88	0.004	55	0.018

4 RESULTS AND DISCUSSION

Due to the limitations of extension, only part of the results is presented here. The hydrograph in January is clearly observed with daily and weekly peaking patterns in the initial point of simulation (x=0). However, the peaking square waves are "damped" with increasing distance downstream (Figure 2). Hydropeaking square waves are diffused and attenuated with distance of the location at longitudinal direction is calculated as water depth dramatically drops into half of the initial peaking values.

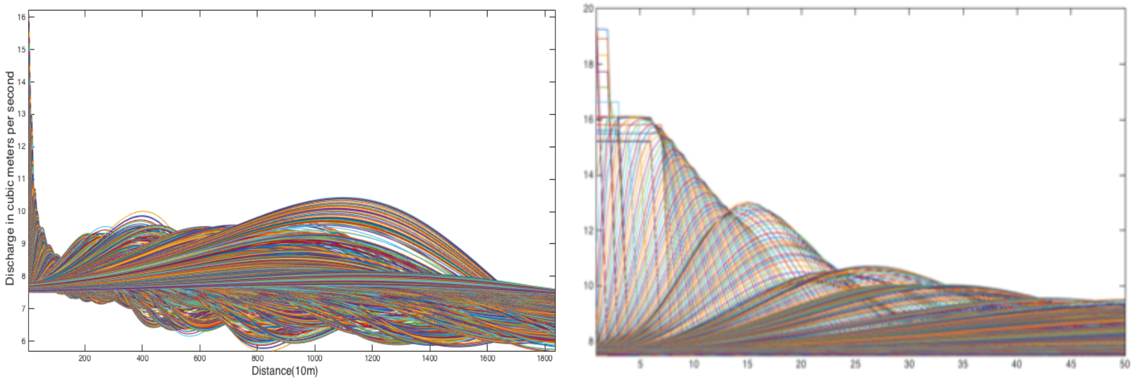

Figure 2. Analytical comparison of the longitudinal distance ($X_{\_wDeca}$) where water depth decreases dramatically to half of the initial hydropeaking depth. Y-axis is the analytical water depth for simplicity of results illustration.

Together with the diffusion coefficient, the reduction in the hydrodynamic square wave amplitude is affected by geomorphologic parameters as well as by the variations of water depth and river discharge. Results of $X_{\_wDeca}$ for the four sections described in part 3 are compared to provide an idea of spatial variations with geomorphology characteristics. Although it has the smallest value of Manning's coefficient, section 2 showed the largest distance of $X_{\_wDeca}$ (160.574 m), with double measurement of river width and lower slope greatly affecting the flow velocity and retention time of the river flow. Comparing the river section 1 and 3, river width plays the most important role among the three main factors. As the channel slope does not differ too much here, Manning's coefficient of riverbed materials and morphology is the second most important variable in influencing the longitudinal decay of the hydrowave. Further analysis of diffusion coefficient distribution will help us discover its seasonal variations and hydropeaking characteristics.

5 CONCLUSION

Based on advection-diffusion theory, hydro- and thermal dynamics wave are simulated and characterized along the river mainstream of a hydropeaking-affected river. Diffusion coefficients and half depth attenuation of longitudinal decay distance is analysed among varied spatial and temporal settings. Given the enormous amount of natural and human-affected riverine systems in the Alps areas, it is important to understand the mitigation effects of hydropower operation-induced hydrodynamics and thermalpeaking waves along the river. This research provides a method for characterization of artificial hydro-thermal regime alterations within a variety of geological and climatic settings. The application of this new methodology will build essential information for assessing the hydropower development of the alpine river systems through stream temperatures and geomorphological variations.

ACKNOWLEDGMENTS

This project has been funded with support from the European Commission, under the program of SMART Erasmus Mundus Joint Doctorate (EMJD). The authors would like to thank the Swiss Federal Office of the Environment (BAFU) and Swiss Federal Office of Energy who provided the data.

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