Impacts of hydropower station daily regulation on flow regimes downstream

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Abstract A hydropower station's daily regulation may change river natural daily runoff and river habitat characteristics, and thus could influence the composition, structure and function of the biocommunity. Based on characteristics of the hydropower station's daily regulation and concepts of ecohydrological parameters, hydrologic indices on the basis of the time series of hourly water level were applied to elucidate the influences of hydropower station daily regulation on streamflow. The attributes of those daily flow pulses, such as magnitude, rate of change, timing and duration, generated by the hydropower station, were quantified. The results of the study provides references for the assessment of impacts of altered flow regimes on riverine ecosystems due to hydropower stations' daily regulation.

Key words hydropower station's daily regulation; flow regime; hydrological indices

INTRODUCTION

The flow regime is the key driver of the river ecosystem, and the alteration of flow regimes is often claimed to be the most serious and continuing threat to ecological sustainability of rivers and their associated floodplain wetlands (Bunn *et al*., 2002; Poff *et al*., 2010). The natural river runoff is basically uniform in one day (except for the flood season), but daily regulation of the hydropower station could generate rapid diurnal changes in flow by the rapid release of water from the reservoir during peaking power generation, which is to satisfy the daily peak demands (Tang *et al*., 2008; Yang *et al*., 2010). This unsteady flow can cause sudden increases and decreases in flow, moreover, with rapidly reversing cycles of wetting and drying of the littoral zone along the river's edge. Muun *et al*. (2002) suggested that benthic invertebrates are vulnerable to rapid diurnal changes in flow, and river reaches influenced by hydroelectric dams' daily regulation are typically characterized by species-poor macroinvertebrates. The drastic reduction of striped bass populations in Roanoke River was partly attributed to losses of benthic fauna severely affected by the greater frequency of hydrograph pulses, rises and falls (Richter *et al*., 1996; Chen *et al*., 2005). Seed germination and growth in floodplain wetlands could also be dramatically influenced by the water level fluctuations (Li *et al*., 2002).

A number of biologically relevant hydrologic indices have been developed to quantify flow characteristics. Different researchers focused on different components of the flow regime, such as average flow conditions, variation in mean daily flow, predictability of flows, skewness in flow and peak discharges, short-term estimates of flood frequency, slopes of flood-frequency curves, seasonal distributions of monthly flows, flow and flood frequency duration curves, and time series of annual discharge, etc. For instance, the commonly used Indicators of Hydrologic Alteration (Richter *et al*., 1997) mainly concerns five critical components of the flow regime that regulate ecological processes in river ecosystems: the magnitude of flow, frequency of occurrence of flows above a given magnitude, duration of time associated with the specific flow conditions of interest, timing or predictability of flows of a defined magnitude, and the rate of change or flashiness of flows.

Usually studies of biologically relevant hydrological indices are at the macro-scale, using daily or monthly hydrological data since hydrological data of meso and micro scale such as hourly data, are usually unobtainable. However, hydropower stations' daily regulation could change the hourly flow regime and produce sharp flow pulses of different magnitude downstream in one day. Based on an ecological concept of macro-scale hydrological indices, such as magnitude and duration of flow events, this study attempts to quantify the influences of hydropower stations' daily regulation on streamflow by hydrological indices, on the basis of the time series of hourly water level collected by water-stage automatic recorders at hydrological stations. In doing this analysis we hope to help stream ecologists to better understand and predict the impact on riverine biota of altered flow regimes due to hydropower stations' daily regulation.

Fig. 1 Schematic diagram of the three tributaries in the upper reaches of Shuiyang River.

Case study sites

Shuiyang River is a main tributary to the Yangtze River, located in the southwest of Anhui Province, stretching 254 km. The catchment area covers 10 305 km^2, the total head is 503 m, and the average width of the river ranges between 60 and 130 m. There are three tributaries upstream: Dongjin River, Xijin River and Zhongjin River (Fig. 1). Among these the Xijin River is the largest, in terms of length and the catchment area. The Gangkouwan reservoir is built on the Xijin River, and it controls an upstream catchment area of 1120 km^2, with a total storage capacity of 9.41 million m^3, and the installed capacity of the hydropower station amounts to 60 MVV. Gangkouwan Reservoir is a large reservoir with multi-objective development functions, such as flood control, power, water supply, farming, shipping, tourism development and others. Both the Dongjin and Zhongjin rivers currently have no water conservancy projects.

DATA AND METHODS

The data used in this paper includes hourly water level and daily rainfall of the Helixi hydrological station on the Dongjin River and the Gangkouwan hydrological station on the Xijin River below the Gangkouwan Reservoir in the years 2006–2011. The hydrologic indices used to statistically characterize hourly hydrologic variations induced by the hydropower station's daily regulation were as follows:

(1) **The frequency of daily flow pulses** The pulse frequency is reflected by days of peak load per month. Generally the pulse frequency is different with the different coming water periods such as low, high and normal flow seasons.

(2) **The magnitude of daily flow pulses** The pulse magnitude can reflect the degree of the change of the water level and discharge below a dam. For example, the maximum daily rise rate reflects the sudden change of flow pulse caused by the hydropower station's peak load dispatching and the daily change of water level reflects the change of water level downstream.

(3) **The duration of time and the timing of daily flow pulses** The pulse duration reflects the different shapes of the flow pulse and it is related to the hydropower station's position on the power system load diagram. Because the electric system's daily load is composed of the peak load area, lumbar load and base load area, different load types change over time. Therefore, when the hydropower station's position on the power system load diagram is different, it can lead to

different shapes of the flow pulse in the downstream channel. For example, as the large scale of the hydropower station, which holds the post of system's peak load, it can lead to the sudden change of the discharge via the hydroturbine at day or night and the violent change of the water level and discharge in the downstream channel, and form a flow pulse with short duration and sharp peak shape. The timing of occurrence of the highest and lowest water conditions for the peak load dispatching days provides another measure of ecological disturbance, and can influence the degree of stress and mortality with extreme water level conditions.

RESULTS AND DISCUSSIONS

Comparison of hourly water level change between rivers with and without hydropower station daily regulation

Since 2005, Anhui Provincial Bureau of Hydrology has collected hourly water level by automatic water-stage recorders at hydrological stations. To elucidate the hourly water level fluctuations caused by daily peaking power generation, the Daily variation range (DVA) of water level, which is the maximum hourly water level minus the minimum hourly water level during a day in 2006, were compared (Fig. 2) at Helixi station on the non-regulated Dongjin River and Gangkouwan station on the Xijin River below the Gangkouwan Reservoir. The correlation coefficient for rainfall between the two stations is 0.80. In this paper, natural or artificial water level fluctuations were not differentiated. From Fig. 2 it can be seen that the daily variation of the Helixi station during the flood season is obvious and the water level is rather stable during the dry season. At the Gangkouwan station downstream of the reservoir, the water level rises and falls steeply during certain days of each month whatever the flood season or dry season, which forms flow pulses with close amplitude and the disappearance of the natural flood pulse can be observed.

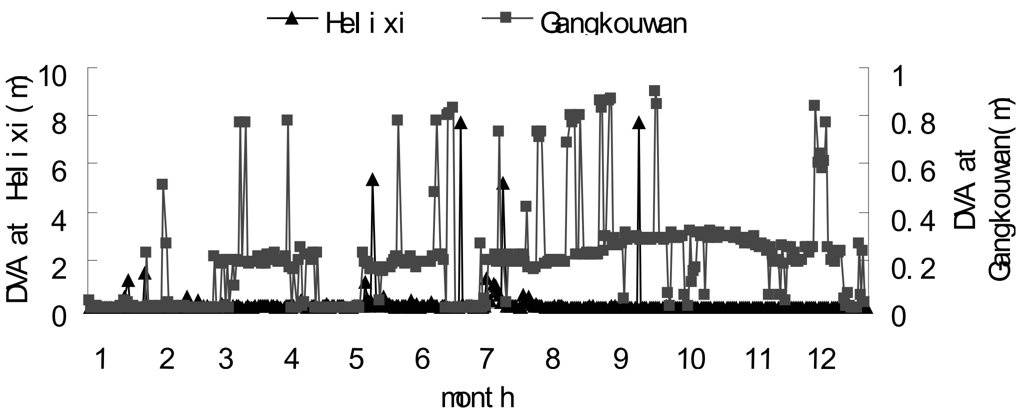

Fig. 2 Daily variation range (DVA) of water level at the study stations in 2006.

The average number of days in which water level fluctuated and average DVAs for these days for each month were computed for Gangkouwan station and Helixi station during 2006–2010. Results are shown in Figs 3 and 4. Days in which water level fluctuated are defined here as those days within a year in which water level is above the base flow according to the hourly water level frequency curve. It can be seen from Figs 3 and 4 that values of these two parameters are quite even for the Gangkouwan Station, but they clearly exhibit a seasonal pattern for the non-regulated Helixi Station.

Quantitative evaluations of hourly water level change downstream the reservoir

The largest change rates in water level from one hour to the next were defined as maximum rise rate (MRR) or maximum fall rate (MFR) according to the change direction of the water level.

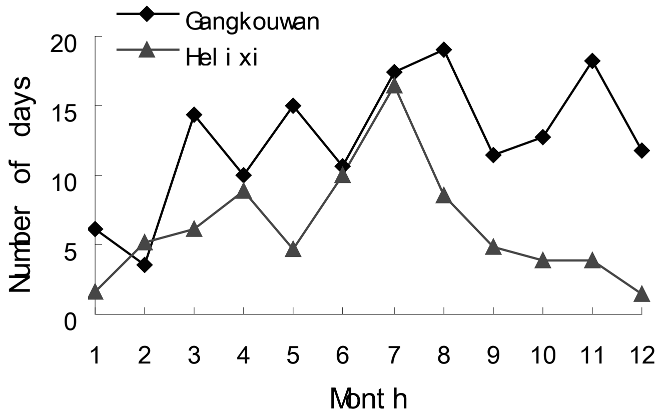

Fig. 3 Average number of water level fluctuation days at the study stations.

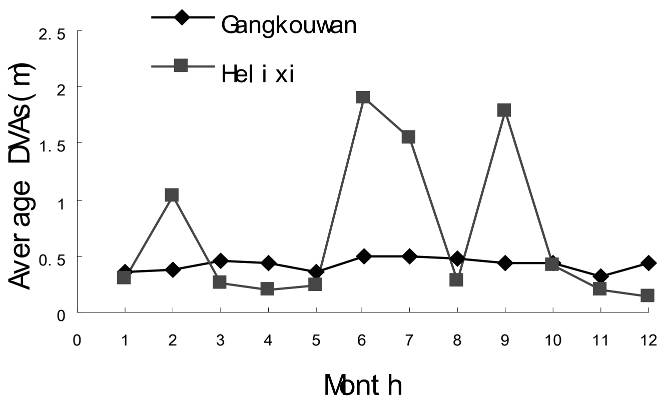

Fig. 4 Average Daily Variation Range of water level at the study stations.

These two parameters could reflect the abruptness of water level fluctuation caused by the peaking power generation. Values of average MRR are between 0.27 and 0.42 m/h for all months excluding February, in which the value is 0.17 m/h and comparatively less. Values of maximum MRR are between 0.60 and 0.77 m/h for all the other 10 months, excluding January and February in which the values are 0.47 m/h and 0.23 m/h, respectively. Values of average MFR are between 0.27 and 0.42 m/h for all the months.

The timing of occurrence of the highest and lowest water conditions for the peak load dispatching days provides another measure of ecological disturbance. Most daily maximum rise rates happened in the morning. The average pulse duration could reflect the time length during which the river downstream maintains comparatively high water level and thus the floodplain is inundated. The smaller the pulse duration is, the sharper the flow pulse. Most average pulse durations in the 12 months during 2006–2010 are less than 4 h. The maximum pulse duration is approx. 10 h and occurred in the dry season. Usually water level should be quite stable and the floodplain should not be inundated during the dry season, but reservoir operations for daily peaking power generation could dramatically change the wetting and drying cycles of the littoral zone downstream.

The results of the daily water level change analysis for the Xijin River reflect the effects of Gangkouwan Reservoir operations for daily peaking power generation. Although elucidation of daily water level fluctuations alone says little about the degree to which biologic patterns and processes may degrade in response to such fluctuations, the results will aid ecological researchers in formulating hypotheses about the hydrological causes of various forms of ecosystem modification by revealing the direction and magnitude of water level fluctuations. Further work to interpret and document species- or community-specific responses to the daily water level fluctuations is urgently needed for the protection of the river ecosystem.

CONCLUSION

A hydropower stations's daily regulation generates abrupt daily flow pulses downstream. The attributes of these daily flow pulses downstream have been adequately quantified by hydrological indices, including the frequency of flow pulses, the timing and duration of flow pulses, and the magnitude of flow pulses, on the basis of hourly water level data. At present little is known about the ecosystem degradation in response to such hydrological alterations, and further studies to investigate the biological responses are urgently required. However, the outputs presented in this paper do provide some guidance for the meso-scale assessment of impacts of hydropower stations's daily regulation on the flow regime of river ecosystem.

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