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Downstream effects of a hydropeaking dam on ecohydrological conditions at subdaily to monthly time scales

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ABSTRACT

Human-altered flow regime is often claimed to be one of the most serious and continuing threats to aquatic biodiversity in streams and rivers. It is commonly found that both seasonal and subdaily flow patterns are changed below hydropeaking dams due to the multifunctions of the reservoirs such as flood control and water supply. The aim of this paper is to comprehensively quantify the degree of ecologically relevant hydrologic alteration downstream of Gangkouwan Reservoir, focusing particularly on the subdaily flow variation induced by hydropeaking operations. The method is based on the assessment framework set by the indicators of hydrologic alteration (IHA). Hydrologic parameters in groups 1–3 of the IHA were adopted to assess the degree of hydrologic alteration at daily to monthly time scales and based on a daily mean flow data series for both the pre- and post-impact periods. A set of biologically relevant hydrologic parameters based on post-dam hourly flow data, including magnitude and duration of baseflow, magnitude and duration of peaking flows, frequency of peaking flows and ramping rates, were proposed to depict subdaily flow pulses and water condition changes induced by hydropeaking. The results show that Gangkouwan Reservoir made the intra-annual distribution of runoff more consistent, reduced annual peak discharges, and changed the timing of the yearly maximum. The monthly distribution of these hydrologic parameters at the hourly temporal scale provides detailed information on ecologically significant features of the subdaily flow variation induced by hydropeaking operations. This paper provides useful guidance for further investigations on responses of river biota to hydropeaking and provides guidance for suggesting mitigation measures against hydropeaking effects.

1. Introduction

The flow regime is the key driver of the river ecosystem, and human alteration of flow regimes is often claimed to be one of the most serious and continuing threats to ecological sustainability of rivers and their associated floodplain wetlands (Bunn and Arthington, 2002; Poff and Zimmerman, 2010; Benjankar et al., 2012). Hydropeaking due to the operations of storage hydropower plants produces diel flow fluctuations downstream of the water releases from the turbines (Munn and Brusven, 1991; Moog, 1993; Gore et al., 1994). Such subdaily flow fluctuations create highly unnatural discharge phenomena in terms of flow magnitude, duration, sequence and frequency, when compared to natural discharge variations. As a result, the water quality, fluvial geomorphology, riparian vegetation, macroinvertebrate and fish communities downstream of reservoirs can be dramatically affected (Valentin et al., 2006; Munn and Brusven, 1991; Cushman, 1985; Moog, 1993; Young et al., 2011).

A sound hydrological analysis of human-altered flow regimes is necessary to understand the ecological effects of dams on a specific stream or river. A number of biologically relevant hydrologic indices have been developed and applied to quantify hydrologic alterations associated with dam operations (Poff et al., 1997; Richter et al., 1996; Clausen and Biggs, 2000). 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 the time series of annual discharge (Olden and Poff, 2003).

Most hydrologic indices can work with any regular-interval hydrologic data such as monthly mean, daily mean, and hourly water conditions (Richter et al., 1996). However, most studies of dam impacts on river hydrological regimes use data from daily mean water conditions to estimate hydrologic indices. Subdaily flow variation and associated ramping rates induced by hydropeaking

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may be masked by mean daily flow values (Zimmermana et al., 2010). Some metrics specifically quantifying different facets of subdaily flow variation can be found in the literature such as hourly minimum flows, maximum hourly ramping rates and the coefficient of variation of hourly flows (Zimmermana et al., 2010). Few studies have systematically and comprehensively characterized the ecologically relevant hydrologic alteration at the subdaily time scale induced by hydropeaking operations, in part because describing rapid subdaily flow fluctuations requires data from short intervals (e.g., hourly), but long time series of short-interval hydrologic data are usually unavailable (Zimmermana et al., 2010). However, changes in the frequency, magnitude, time, duration and change of rate of subdaily flow fluctuations downstream of dams have been shown to reduce abundance, diversity, reproductive success and survival of aquatic and riparian species (Niu and Insley, 2013). Assessing the flow alterations at the subdaily time scale is important for river managers and ecologists to investigate the ecological effects of hydropeaking.

The aim of this paper is to comprehensively investigate the downstream effects of a hydropeaking dam on the ecohydrological conditions at the monthly, daily and hourly temporal scales, based on the assessment frame set by the indicators of hydrologic alteration. Using daily mean and hourly flow data, the hydrologic regimes from pre- and post-impact timeframes were compared, as well as the hydrological regimes upstream and downstream of the reservoir (i.e., unimpacted vs. impacted). This study particularly focuses on the subdaily hydrologic alterations normally restricted to hydropeaking operations including minimum flows, peaking flows, initial surge, and fluctuating flows (Gore and Nestler, 1990). A set of hydrological indices based on hourly flow data, including magnitude and duration of baseflow, magnitude and duration of peaking flows, frequency of peaking flows and ramping rates, were supplemented to depict the unique subdaily flow characteristics induced by hydropeaking operations. The application of the proposed methodology would allow understanding and prediction of the impact of altered flow regimes on riverine biota due to hydropeaking operations in a subtle and comprehensive way.

2. Study area and data

The Shuiyang River is a main tributary of the Yangtze River, approximately 254 km long, in southwestern Anhui Province in China. It has a total catchment area of approximately 10,305 km^2, a total head of approximately 503 m, and a width ranging from 60 to

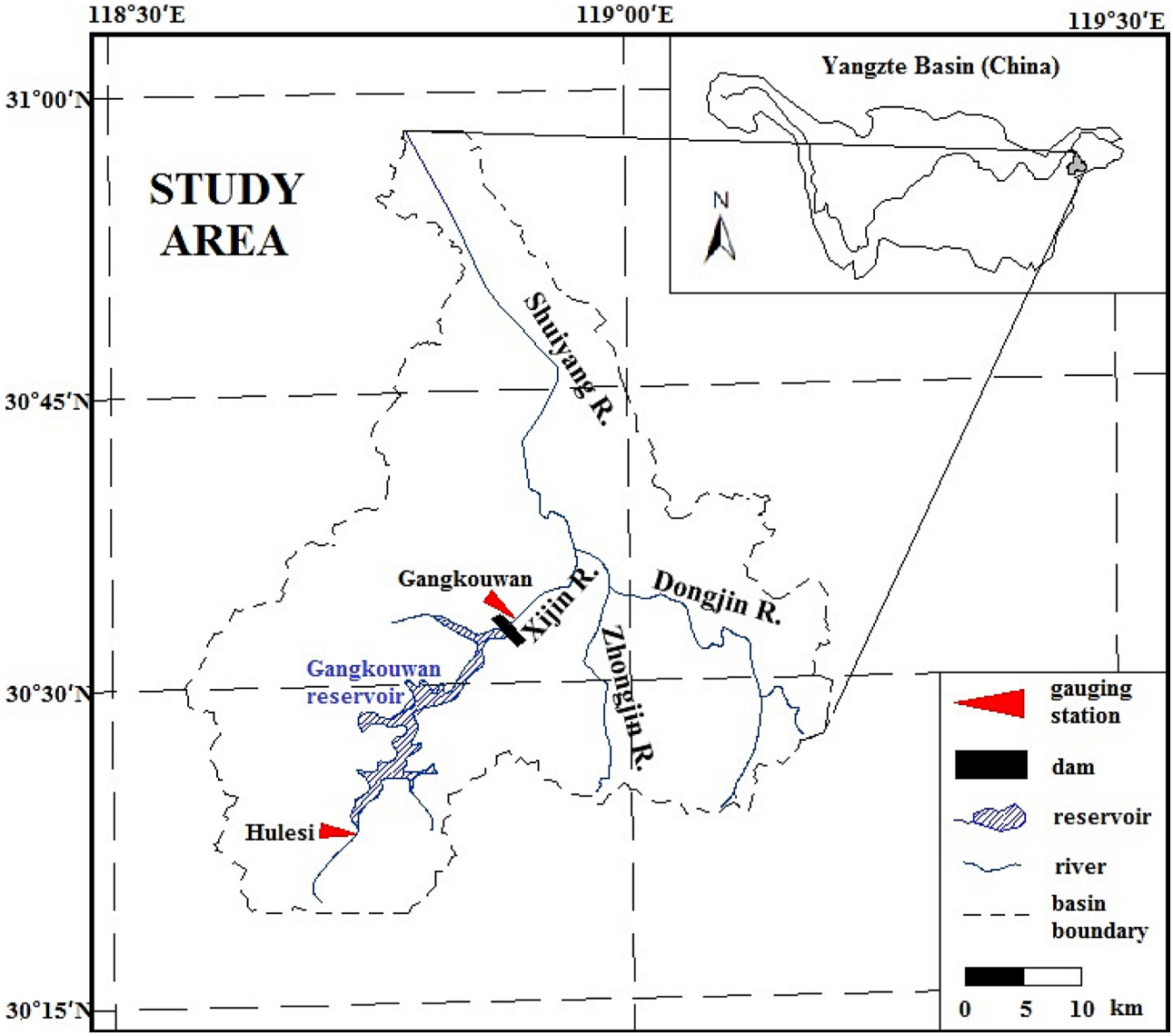

Fig. 1. Sketch of the Shuiyang River and its three tributaries.