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Prediction of river ecological integrity after cascade hydropower dam construction on the mainstream of rivers in Longitudinal Range-Gorge Region (LRGR), China

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ABSTRACT

Dam construction is considered the major factor contributing to significant modification of river ecosystems. The related ecological effects of these constructions on flow patterns, water quality, sediment etc. have led to increased concerns in recent years. Most of the works so far focus on the assessment of vulnerability, risk, and damages to single factors, such as soil conservation, fish reproduction or vegetation. Few works have been done on to analyzing and predicting the changes of the river ecosystem integrity (*REI*). Taking three important international rivers, Lancang River, Nu River and Yuan River in LRGR as a case study, the relationship between cascade dam construction and *REI* is analyzed. A model of the cascade dam construction and the *REI* is developed on Lancang River after cascade construction, and then it is applied on the Nu River and Yuan River to predict the changes of *REI* after the planned cascade construction. The results show that there are significant relationships between the cascade construction and the change of the *REI*. Before the cascade development, *REI* index of Nu River is the highest with a value of 0.844. Yuan River, the worst of the three before the cascade construction (0.719), is found to be the best one after the cascade construction (0.389). After the cascade construction, the *REI* index value of the Lancang River is likely to dramatically decrease from 0.825 to 0.274.

1. Introduction

It is reported that 2.2% of the world's primary energy is generated by hydropower and approximately 70% of the world's rivers is intercepted by large reservoirs (Kummu and Varis, 2007). Dam construction is considered the major factor contributing to significant modifications of river ecosystems (He et al., 2004). Thus, human disturbances on river ecosystems have induced increasing concerns over the last few decades (Bockelmann et al., 2004).

Dam construction results in changes of hydrology, river morphology and habitat (Williams and Wolman, 1984; Vörösmarty et al., 2003; Hu et al., 2008). Dams can alter the river's natural flow patterns and possibly increase the flow fluctuation (He et al., 2007). Since the operation of Hoover Dam and others in the United States and Mexico, little water reaches Colorado's estuary in the northern Gulf of the California (Lavín and Sánchez, 1999; Schöne et al., 2003). The changed flow patterns can delay the arrival of floods and shorten their period (He et al., 2006). Due to the construction of dams and reservoirs, the water renewal time of rivers has significantly increased from 20 to 100 days (Kummu and Varis, 2007).

Williams and Wolman (1984) report that sedimentation in reservoirs and scour in the river-bed in downstream reaches are the major reason for channel morphology changes. Dams can cause significant discontinuities in the transportation of sediments (Rãdoane and Rãdoane, 2005). It is estimated that 1% of the existing storage volume in the world is lost each year to sedimentation (Kummu and Varis, 2007). Susceptibility to sedimentation of the reservoirs depends on the characteristics of the sediment, inflow, velocity, reservoir and its management. Sediment trapping efficiencies for almost half of the reservoirs are about 80% or more (Vörösmarty et al., 2003). Commonly, the trapping efficiency of large reservoirs (volume $>10^7$ m^3) is greater than 99% (Williams and Wolman, 1984; Graf, 2005), while that of small reservoirs ranges between 10% and 90% (Brune, 1953).

Dam construction significantly alters the physical characteristics of habitats, including continuity, flow distribution, organic matter, water velocity, water depth and water temperature in the

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Fig. 1. Distribution of dams on mainstreams of Lancang River, Nu River and Yuan River in LRGR.

reservoir, and thus disturbs the biota associated with the reservoir (Tiffan et al., 2002; Tiemann et al., 2004; Tomsica et al., 2007). Alteration of the physical habitat due to dam construction will disrupt the life cycles of stream organisms by masking or eliminating cues for spawning, obstructing migration routes, altering thermal regimes or modifying rearing habitats (King et al., 1998; Franssen et al., 2007). The changes in flow patterns and water temperature potentially change the spawning habitat for fishes (Tiffan et al., 2002). Consequently, the population and diversity of fish and benthic organisms significantly change compared to the assemblage before dam construction, as many organisms adapt their traits to match these changed environmental conditions (An et al., 2002; Franssen et al., 2007). Cascade construction has extensive influences on river ecosystems in more aspects than a single dam.

The Longitudinal Range-Gorge Region (LRGR), composed of the Hengduan Mountains that are related to the Tibetan uplift and the adjacent mountain-valley regions in south-north direction, lies in south-western China (He et al., 2005) (Fig. 1). Four famous transboundary rivers flow through the LRGR, i.e., Yuan-Red River, Lancang-Mekong River, Nu-Salween River and Irrawaddy River. For three of them, cascade hydropower dams have been planned and some are already constructed on the main channel (Fig. 1). The development of cascade hydropower dams may alter the structure and function of river ecosystems. The related ecological effects of these constructions on flow patterns, water quality, sediment etc. have led to increased concerns in recent years, especially in the Lancang River Basin.

The imposition of dams can cause rapid environmental changes. The Manwan Dam on the main stream of the Lancang River has had substantial ecological effects in the reservoir and downstream of this dam. By 1996, three years after the closure of Manwan Dam, siltation had increased the elevation of the reservoir bottom to a level 30 m higher than before construction (He et al., 2004). Water quality had degraded (Zhang et al., 2005) and surface water temperature in the reservoir was higher than before the dam construction. He et al. (2006) report that the operation of Manwan and Dachaoshan Dams (see Fig. 2) influenced the flow patterns of the Lower Mekong River, though the alteration was not a major factor. However, once the two largest dams, Xiaowan and Nuozhudu, are completed, the seasonal regulating capacity of Lancang Cascade will reach 100%, which will result in obvious effects on the distribution of water volumes (He et al., 2006). Similar results were found by Li et al. (2006). Kummu and Varis (2007) propose a theoretical method to predict the amount of sediment trapped in the reservoirs on the Lancang-Mekong River.

Ecological engineering strategies aim to provide a sustainable ecosystem that benefits both human society and the natural environment. Dam construction can benefit human society through power generation, facilitating navigation and controlling floods (Bombino et al., 2006). Dam construction has both negative and positive effects on the river ecosystem. This paper aims to evalu-