



Landscape change and hydrologic alteration associated with dam construction

Qinghe Zhao, Shiliang Liu*, Li Deng, Shikui Dong, Cong, Wang, Zhifeng Yang, Juejie Yang

State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, China

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ABSTRACT

Characterizing the landscape changes and hydrologic alterations associated with dam construction is very important for watershed management. This paper presents a case study of the Lancang River in Yunnan Province following dam construction. The landscape patterns and dynamics indicate the fragmentation, shape, and diversity of the river in 1980, 1990, and 2000. The Range of Variability Approach (RVA) is used to evaluate the degree of hydrologic alteration (DHA) using 44 years (1957–2000) of hydrologic data. The results indicate that the midstream and downstream landscapes were affected by dam construction, becoming more complex and fragmented during the 1980–2000 period; the upstream area was not influenced by dam construction and the reservoir impoundment exhibited less change. The variability in maximum runoff occurrence in the post-dam period was less than that in the pre-dam period. The integrated DHAs of the Jiuzhou (upstream), Gajiu (midstream), and Yunjinghong (downstream) stations were relatively low, reaching 26.28%, 33.40%, and 37.14%, respectively. However, the alteration became obvious in the midstream area, and the situation worsened when the river was simultaneously influenced by dam construction and other human activities (downstream). The results of the regression analysis show strong relationships of landscape metric changes with DHA, and the forestland and water areas with DHA. The DHA increased along with the aggravation of landscape fragmentation, the complexity of the landscape shape, and the diversification of the landscape.

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1. Introduction

Excessive anthropogenic activities such as agricultural land reclamation, industrial development, road network expansion, and dam construction play important roles in landscape change and hydrologic alteration (Xu et al., 2007; Liu et al., 2008; Yang et al., 2010; Bergerot et al., 2011). Dams, which are constructed for seasonal flood control, navigation, and generation of hydroelectric power, are often cited as the most significant impact on rivers around the world, reducing the connectivity of rivers, fragmenting watersheds, causing changes to hydrological processes, and resulting in downstream river channel erosion (Tiemann et al., 2004; Hu et al., 2008). Therefore, concerns about the effects of dam construction on the environment have increased with the increasing number of dams in recent years (Jansson et al., 2000; Chovanec et al., 2002; Tockner and Stanford, 2002; Dudgeon, 2005). Early studies show that dam construction can affect a variety of processes in both inner (Ellery et al., 2003; Hu et al., 2008; Walters et al., 2009; Zeilhofer and De Moura, 2009) and outer river areas (Dudgeon, 2005; Zeilhofer and De Moura, 2009; Ouyang et al., 2010).

In the outer river area, landscape changes associated with land use and land cover change are the most obvious impacts of dam construction (Ouyang et al., 2010), and have a fundamental reciprocal relationship with ecological processes (Turner, 1989). Therefore, the investigation and quantification of landscape changes caused by dam construction in the outer area are the domain of landscape ecology and the basis for sustainable environmental management. A number of metrics have been developed to measure the influences of human activities on landscape structure (Theobald, 2010), such as the total land area and individual land use type areas, patch density, edge density, perimeter-to-area ratio, landscape diversity, and so on (Palmer, 2004; Morgan et al., 2010). Usually, researchers select metrics for quantification of landscape changes based on specific categories (e.g., fragmentation, shape and diversity) to avoid linearity and redundancy between metrics.

Dam construction can affect the hydrologic regime in the inner river area more immediately than the landscape in the outer river area (Nilsson and Berggren, 2000; Walter and Merritts, 2008). Dam construction can block the continuity of hydrology, disrupt sediment transport and fish migration by modifying the seasonality of flows, and alter surface and subsurface water levels, changing the magnitude, duration, frequency, timing, predictability, and variability of flow events (Nilsson and Berggren, 2000; Ouyang et al., 2011). These impacts may lead to a loss of biological diversity and decrease the ecological functions in an aquatic ecosystem

* Corresponding author. Tel.: +86 10 13522671206; fax: +86 10 58800397.
E-mail address: shiliangliu@bnu.edu.cn (S. Liu).

(Postel, 1998; Isik et al., 2008; El-Shafie et al., 2009). Accordingly, it is essential to understand the impact of dam construction on aquatic systems in the inner river area. Recently, the majority of researchers in China and abroad have explored the impacts of building dams with a focus on hydrological changes in the inner river area (Richter et al., 1998; Wang et al., 2005; Lajoie et al., 2007; Ouyang et al., 2011). These studies demonstrate that the hydrologic alterations and related environmental impacts of dam construction have become a main concern in hydrological development plans (Richter et al., 1998; Lajoie et al., 2007; Ouyang et al., 2011). Regarding hydrologic alteration, many indicators have been developed from the hydrological monitoring data to quantify flow characteristics that are sensitive to human perturbations (Yang et al., 2008; Chen et al., 2010). Although over 170 hydrologic indicators have been developed to describe different components of flow regimes, which hydrologic indicators to use to summarize flow properties analogous to the use of the widely accepted metrics is still unclear (Gao et al., 2009). Comparatively, the Indicators of Hydrologic Alteration (IHA) comprising 32 parameters developed by Richter et al. (1996) are more commonly used worldwide (Shiau and Wu, 2006; Magilligan and Nislow, 2005; Hu et al., 2008; Chen et al., 2010). Further, Richter et al. (1996) introduced a useful approach referred to as the Range of Variability Approach (RVA) based on the 32 Indicators of Hydrologic Alteration (IHA) to quantitatively evaluate the degree of hydrologic alteration (DHA) induced by human disturbance. This method has been shown to be a practical, and effective way to assess the DHA caused by dam construction and other human activities (Maingi and Marsh, 2002; Magilligan and Nislow, 2005; Kummur and Varis, 2007; Yang et al., 2008; Zeilhofer and De Moura, 2009; Chen et al., 2010).

In general, dam construction has great impacts on landscape and hydrology, so it is of scientific importance to investigate and evaluate the landscape changes and hydrologic alterations induced by dam construction. Nevertheless, many previous researchers focused on quantifying land use change or hydrological alterations without investigating the interrelation between landscape changes and hydrological alterations under the influence of dam construction. However, it is inevitable that land use changes such as conversion of forest to cropland will directly influence the regional hydrologic characteristics and processes (Zacharias et al., 2004; Verbunt et al., 2005; Ouyang et al., 2011). Therefore, the objectives of this study are to (1) appraise the magnitude of the influence that dam construction imposes on local landscape and hydrology, and (2) reveal the relationships between landscape change and hydrological alteration in the Lancang River in Yunnan Province (internationally known as the Mekong River) where large dams are being constructed or have already been completed.

2. Materials and methods

2.1. Study area

As the largest international river in Asia, the Lancang River passes through seven climatic zones, crosses different geographic environments and connects different cultural, social, and economic communities (Liu et al., 2008; Hu et al., 2009). The average rainfall in the Lancang River basin is about 500 mm in the southeast and 250 mm in the northwest parts of the river. The Lancang River exhibits strong seasonality of runoff, with 70% of the overall annual water flow normally occurring in August and September (Jacobs, 2002). Additionally, the Lancang River has a main channel drop of 5000 m, and the portion of the river in Yunnan Province has a drop of 1780 m and an average gradient of 0.15% (Jacobs, 2002; Liu et al., 2008). Therefore, the unique natural and geographical features in addition to plentiful hydraulic resources bring many advantages

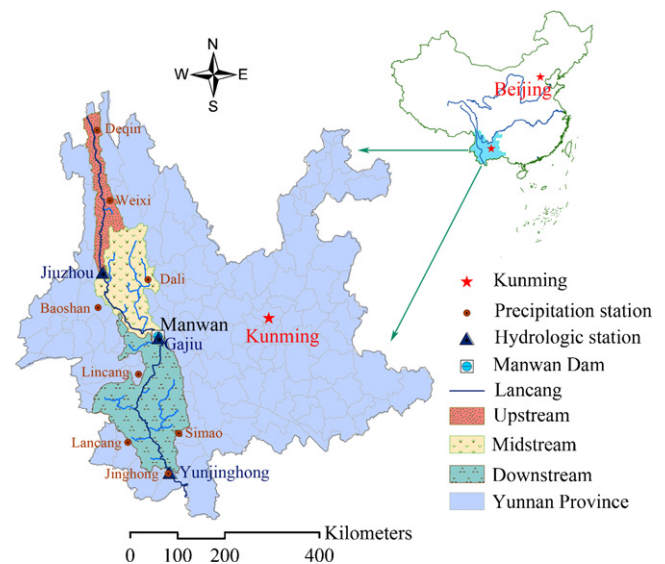


Fig. 1. Location of the Manwan Dam and gauging stations in the Lancang Basin, Yunnan Province.

for hydropower cascade development in this area (He et al., 2005, 2006).

The study area is a section of the Lancang River in Yunnan Province, wherein the lower control point is the Yunjinghong gauging station and the upper control point is the entrance of the Lancang River into Yunnan Province (Fig. 1). This area is a key part of the upper stream of the Lancang River where four hydropower dams have been constructed (Xiaowan, Manwan, Dachaoshan, and Jinhong Dams) and several dams and storage reservoirs for hydropower production are under construction or in planning (Wei et al., 2009). The study area was divided into three parts according to the hydrological and topography features (Gan et al., 2002). The section from the inlet to the Jiuzhou station was defined as the upstream area, and was not influenced by dam construction or reservoir impoundment. The section from the Jiuzhou station to the Gajiu station was defined as the midstream area, wherein dam construction and reservoir impoundment were the dominating disturbances to the landscape and hydrology. The downstream area includes the section from the Gajiu station to the Yunjinghong station, and was simultaneously influenced by dam construction and other human activities.

The Manwan Dam, which is the first dam of the Lancang main-stream cascade and the first multimillion kilowatt hydropower station in Yunnan Province, was completed in the middle reach of the Lancang River in Yunnan Province in 1993. The dam is 132 m high, has a crest length of 418 m, and forms a 337.1 m wide water surface reservoir, which is two times more than that of the natural channel. The reservoir area is 23.6 km², which is 2.8 times larger than the area existing prior to dam construction. The total reservoir capacity is 1060 × 10⁶ m³, and the effective capacity is 257 × 10⁶ m³, which is dependent upon seasonal discharge regulation (He et al., 2004, 2005, 2006; Fu and He, 2007; Zhao et al., 2010). The associated hydrology and landscape mosaic of the areas upstream and downstream from the dam have been affected by its construction and operation (He et al., 2004).

2.2. Data and methods

2.2.1. Data

In this study, regional land use data from three periods (1980, 1990, and 2000) were directly extracted from the national land use database acquired from the Data Center for Resources and

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