Journal of Hydrology 529 (2015) 711–722

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Evaluation of ecological instream flow using multiple ecological indicators with consideration of hydrological alterations

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ARTICLE INFO

Article history:
Received 8 April 2015
Received in revised form 17 May 2015
Accepted 31 August 2015
Available online 5 September 2015
This manuscript was handled by Andras Bardossy, Editor-in-Chief, with the assistance of Luis E. Samaniego, Associate Editor

Keywords:
Ecosurplus
Ecodeficit
Indicators of hydrological alterations
Hydrological alterations
Eco-flow regimes
Dam-induced eco-effects

SUMMARY

Dam-induced hydrological alterations and related ecological problems have been arousing considerable concern from hydrologists, ecologists, and policy-makers. The East River basin in China is the major provider of water resources for mega-cities within the Pearl River Delta and meets 80% of annual water demand of Hong Kong. In this study, ecodeficit and ecosurplus were analyzed to determine the ecological impact of water impoundments. Also, D_o and DHRAM were employed to evaluate the degree of alteration of hydrological regimes, and ERHIs were analyzed to evaluate the influence of hydrological alterations on ecological diversity. Results indicate that: (1) the magnitude and frequency of high flows decrease and those of low flows increase due to the regulation of reservoirs; (2) variations of annual ecosurplus are mainly the result of precipitation changes and the annual ecodeficit is significantly influenced by reservoirs. However, ecodeficit and ecosurplus in other seasons, particularly autumn and winter, are more influenced by reservoir regulation; (3) impacts of reservoirs on hydrological regimes and eco-flow regimes are different from one station to another due to different degrees of influence of reservoirs on hydrological processes at different stations. The longer the distance between a reservoir and a hydrological station is, the weaker the influence the water reservoir has on the hydrological processes; (4) ecodeficit and ecosurplus can be accepted in the evaluation of alterations of hydrological processes at annual and seasonal time scales. Results of Shannon Index indicate decreasing biological diversity after the construction of water reservoirs, implying negative impacts of water reservoirs on biological diversity of a river basin and this should arouse considerable human concerns. This study provides a theoretical background for water resources management with consideration of eco-flow variations due to reservoir regulation in other highly-regulated river basins of the globe.

1. Introduction

Variations of instream flow are in close relation with variability and availability of water resources in a river basin and are also relevant for river health and the diversity of fluvial ecological system. Meanwhile, climate changes, human activities, including the construction of dams, diversion structures, levees, among others, significantly alter river behavior. Revenga et al. (2000) estimated that 60% of the world's rivers are fragmented by hydrologic alterations, with 46% of the 106 primary watersheds having been modified by the presence of at least one large dam. China alone possesses nearly half of the total number of dams in the world (Tharme, 2003). What's more, over half of the world's accessible surface water is already appropriated and will be increased to an astounding 70% by 2025 (Postel et al., 1996). It should be noted that impoundments, diversion weirs, inter-basin water transfers, irrigated agriculture, and hydropower generation employed for the exploitation of water resources exercise tremendous impacts on riverine ecosystems (Power et al., 1996; Milliman, 1997; Rosenberg et al., 2000; Zhang et al., 2009, 2012). Further, human-induced hydrological alterations may point to associated implications for fluvial geomorphology, ecological environment and biodiversity of river channels downstream of the dams or water reservoirs (Yang et al., 2006; Schmidt and Wilcock, 2008; Rossi et al., 2009). This is the main reason for consideration of hydrological alterations in the evaluation of ecological instream flow.

Relations between hydrologic indicators and ecological diversity have been extensively studied (e.g. Yang et al., 2008). However,

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http://dx.doi.org/10.1016/j.jhydrol.2015.08.066
0022-1694/

Olden and Poff (2003) summarized more than 170 hydrological indicators based on the published literature to show changes in flow regimes and found that some of these hydrological indicators were redundant and intercorrelated (Olden and Poff, 2003). Richter et al. (1996) proposed 33 hydrological indicators (Indicators of Hydrological Alteration) to show intra- and inter-annual variations of flow regimes and these have been widely used in the analysis of hydrological alterations (Chen et al., 2010; Zhang et al., 2014a). Indicators of Hydrologic Alteration (Richter et al., 1997) have been used in the computation of flow statistics from different release polices in the evaluation of both ecological and economic benefits within a diverted river reach in the Swiss Canton of Graubünden (Gorla and Perona, 2013). The East River, one of the main tributaries of the Pearl River basin, acts as the principle water resources provider for Hong Kong and other mega-cities within the Pearl River Delta. Nearly 80% of the annual water demand of Hong Kong is met by the East River basin. Besides, hydrological processes of the East River basin have been significantly altered and fragmented by water reservoirs. Up to the end of 2006, 896 hydraulic facilities with a total storage capacity of about 19 billion m^3 had been constructed in the basin.

The Xinfengjiang and the Fengshuba water reservoirs were constructed in 1961 and 1974, respectively, with a total storage capacity of 15.83 billion m^3. The construction of these water reservoirs is expected to alter the hydrological processes and may negatively influence the eco-environment and water resources management of the basin (Zhang et al., 2014a).

Analysis of the altered flow regimes due to the damming by reservoirs has been done (e.g. Chen et al., 2010; Zhou et al., 2012) and ecological instream flow of the East River basin (Fig. 1) has been evaluated considering hydrological alterations (Zhang et al., 2014a). However, intercorrelations amongst the 33 hydrological indicators have not been analyzed comprehensively so far (Gao et al., 2009). Furthermore, the existence of intercorrelations amongst the various indicators cannot meet the requirement of optimal manipulation of reservoir water release with consideration of changes in the ecological instream flow (Shiau and Wu, 2006). Considering the importance of variability and availability of water resources and the conservation of fluvial ecological health of the East River basin, multiple hydrological indicators, such as Flow Duration Curve (FDC), ecosurplus and ecodeficit (Vogel et al., 2007), have been accepted for the evaluation of ecological instream flow of the East River basin for purposes of ecologically relevant water resources management. Moreover, an integrative index, D_o, has been used to define the overall degree of hydrologic alteration (Shiau and Wu, 2007). In this case, the objective of this study therefore is to investigate ecological instream flow regimes considering hydrological alterations using multiple hydrological indicators. Results of this study will provide information for understanding ecological instream flow regimes under the influence of reservoirs, optimal water reservoir release and proper exploitation of water resources in the East River basin, China.

2. Data

There are three large-scale reservoirs (Fig. 1), i.e. Xinfengjiang, Fengshuba and Baipanzhu. Table 1 gives information on these reservoirs in terms of construction time span, drainage area, and total water capacity. Daily streamflow data covering a period of 1954–2009 were obtained from four hydrological stations (Fig. 1). Information of these stations, such as exact location and length of hydrological series considered, is given in Table 2. Hydrological data were obtained from the Guangdong Hydrological Bureau of China and no missing data were available. The quality of dataset is firmly controlled before its release. The hydrological series were subdivided into two sections: one before the building of reservoirs and the other thereafter (Table 2) (Zhou et al., 2012; Zhang et al., 2014a). Besides, daily precipitation data from 29 stations covering a period of 1959–2009 were also analyzed (Fig. 1) (Zhang et al., 2013). Missing values were found in daily precipita-

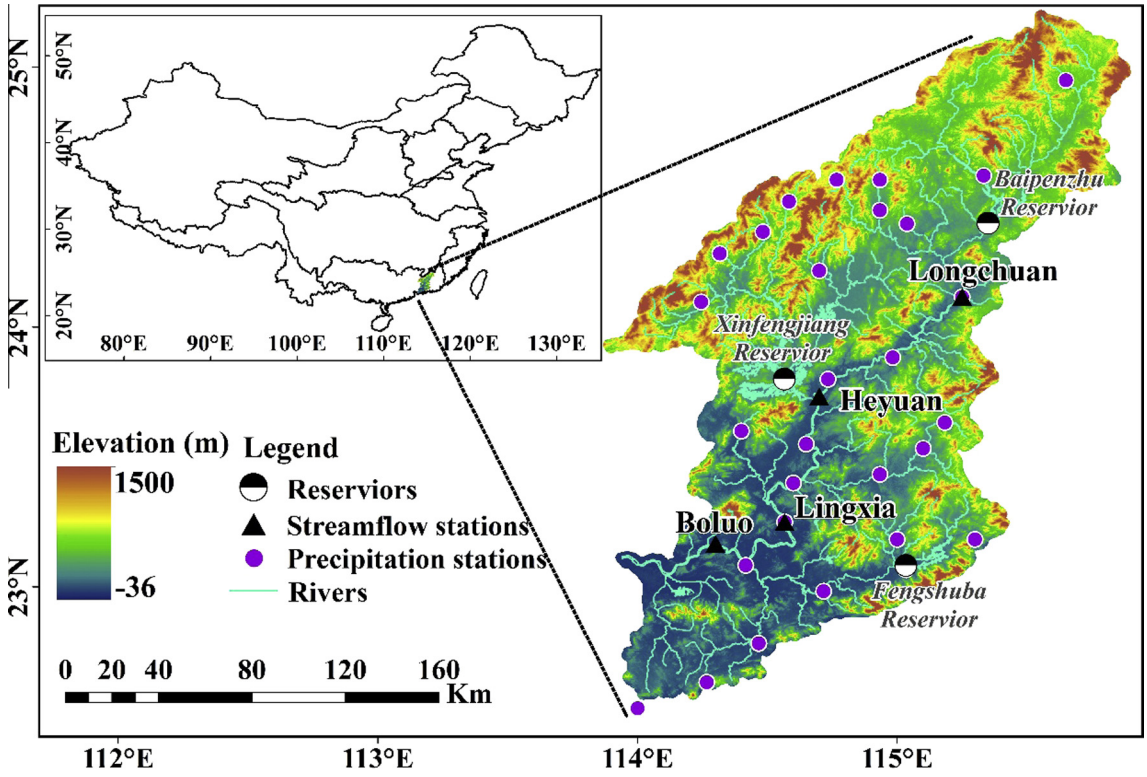

Fig. 1. Locations of precipitation stations, hydrological stations and water reservoirs in the East River basin, China.