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Review

A review of ecological restoration techniques in fluvial rivers

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ABSTRACT

Rivers play an important role in people's living and agricultural production, however, intense human activities have broken the original ecological balance, and affected structures and functions of the river ecosystem. To restore the damaged river ecosystem back to a healthy status, effective ecological restoration measures need to be implemented. The main problems that the damaged rivers face are either the locally altered hydrological processes affected by construction of hydraulic facilities, or the deterioration of water quality resulted from pollution emissions, or both. In this study, ecological restoration techniques of the rivers affected by engineering control or pollution are reviewed respectively. In addition, three kinds of methods, i.e. physical, chemical and biological–ecological methods are introduced in details for the rivers affected by water pollution. At present, the development of river restoration techniques shows the following trends: 1) the scale of ecological restoration is becoming larger; 2) ecological restoration measures are required to meet multiple objectives; and 3) the management of water environment is changing from water quality management to aquatic ecosystem management.

1. Necessity of conducting research on ecological restoration

Rivers, the products from the evolutionary processes of the Earth, are the origin of survival and development of human beings, and closely related to human civilization, culture and history. Rivers serve many functions such as electricity generation, water supply, sediment transport, shipping, food production, sightseeing, and more, hence, they play an important role in people's living and agricultural production (Allan & Castillo, 2007; Pan et al., 2012a, 2012b). With the rapid development of industry and agriculture, the intensity in which human exploit and utilize rivers has gradually increased, thus, rivers have been experiencing great pressures from human activities, and some service functions of rivers even present trends of degradation.

For purposes of flood control, some engineering control measures, such as construction of reservoirs and embankments, river straightening, flood detention basins, and two-graded river channels, have been implemented. For purpose of shipping, hydraulic engineering facilities (e.g. spur dikes, weirs, closure dams, etc.) have been built along river banks to increase the water depth (Zhang et al., 2012). Although some service functions of rivers have been promoted, geomorphic features and local natural hydrological regime are changed. In addition, rivers face another major threat, pollutant discharge, which can shift water from a clear, macrophyte-dominated state to a turbid, algae-dominated state (Fig. 1). Intense human activities have broken the original ecological balance, and affected structures and functions of the river ecosystem. To restore the damaged river ecosystem back to a healthy status, effective ecological restoration measures need to be

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implemented. In recent years, river managers have switched their focus from hard engineering solutions to ecological restoration activities in order to improve degraded waters (Bernhardt et al., 2005; Palmer et al., 2004).

Restoration planning process should be clarified, the restoration goal be identified, and restoration actions be prioritized (Beechie et al., 2008; Bond & Lake, 2003a, 2003b). The first step of a restoration program is to identify the damaged functions of the damaged rivers, the extent of the damage, and the constraints of the river systems, and then the restoration goals need to be prioritized and the restoration measures need to developed. The main problems which the damaged rivers face are either altered hydrological processes affected by construction of hydraulic facilities, or deterioration of water quality resulted from pollution emissions, or both. Effective restoration measures can be taken on the basis of diagnosis results of the threats to rivers.

Ecological restoration is defined as a process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems (Jackson et al., 1995). Linking ecological research and restoration is essential for river restoration (Lake, 2001), which has experienced three stages of development. At the first stage, in the 1950s, "conducting regulation project in order for similar natural river" was proposed in Germany, and river researchers gained a wealth of experience on population restoration. At the second stage, in the 1980s, ecological restoration techniques were gradually applied in large rivers. At the third stage, since the 1990s, as the ecological techniques matured, ecological restoration projects at the basin scale have gradually increased. Previous research on river ecological restoration has been restricted to the rivers disturbed by engineering control (Boon et al., 1992; Chen & Chen, 2007; Down et al., 1995; Hession et al., 2000; Lewis, 2005; Xu & Zong, 2005) or the rivers affected by pollution (Brix et al., 2000; Li, 2007; Skelton et al., 1989; Xu & Zong, 2005). Systematic ecological restoration techniques have not been well documented. The main objective of this paper is to present an overall review on river restoration techniques which have been applied in the past several decades.

2. Ecological restoration of rivers affected by engineering control

Ecological restoration of rivers affected by construction of hydraulic facilities mainly includes two aspects, i.e. restoration of natural hydrological regime and river geomorphological features. Gore and Shields (1995) emphasized the viewpoint that renewal of the hydrological interactions between the main channel, backwaters, and floodplains is central to rehabilitation. Restoration of the natural hydrological process is mainly applied in three scenarios. Firstly, abandoned channels have lost their lateral hydrological connectivity with the mainstreams. Biodiversity, standing crops, and production of aquatic biota would increase by reconnecting the abandoned channels with the mainstreams (Buijse et al., 2002; Pan et al., 2012; Tockner et al., 1998, 1999; Ward et al., 2001). Secondly, construction of dams impedes longitudinal hydrological connectivity (Amoros & Bornette, 2002; Jackson & Pringle, 2010; Mladenovic et al., 2013), and reservoir ecological operations can alter temperature and flow regime to a certain extent (Bednarek & Hart, 2005; Olden & Naiman, 2010; Richter & Thomas, 2007; Stanford et al., 1996). Dam removal is another effective restoration measure, certainly, there are not only opportunities but also challenges (Hart et al., 2002; Roni et al., 2008). Thirdly, restoring the links between surface and ground water flow enhances vertical connectivity and communities associated with the hyporheic zone (Boulton et al., 2007; Jansson et al., 2007; Stanford et al., 1996). Restoration actions may be removing fine sediment deposits that block vertical exchange with the bed (Kondolf et al., 2006; Xu et al., 2012). The restoration zones of river geomorphological features can be divided into two parts, i.e. riparian restoration and river channel restoration.

2.1. Ecological restoration of riparian zone

Due to severe floods in the history, a great deal of effort has been put into developing riparian flood control measures, thus, riparian protection techniques were gradually improved. Traditional materials of riparian slope protection are mainly stone and concrete, which have damaging effects on ecology by isolating the material exchange between soil and water (Hufford & Mazer, 2003;

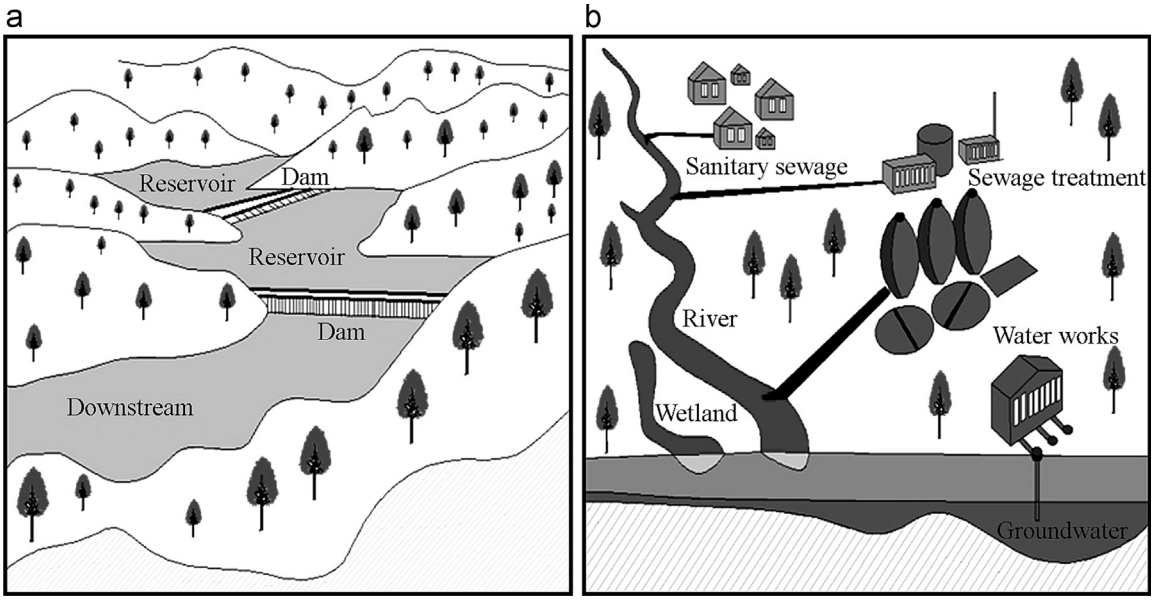

Fig. 1. The major threats which rivers are facing: (a) hydraulic engineering facilities (e.g. dams); and (b) pollutant discharge.