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Research paper

Dynamic vegetation model as a tool for ecological impact assessments of dam operation

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Abstract

This study presented the results of an application of a floodplain dynamic model to the Nakdong River, South Korea. At the Nakdong River, high flows are reduced by dams and the river bed is degraded. Both changes contribute toward the same result: the floodplain is hydraulically disconnected from the main channel and the morphology of the river has been modified. Such changes brought also to a deep modification in the riparian vegetation distribution, abundance and composition. The focus of the study is on the relationship between the hydrology alterations induced by dams and the successional changes in riparian vegetation. More in detail, the study attempts to adapt an existing dynamic floodplain vegetation model to the Nakdong ecosystem characteristics in order to single out what were the effects of the dam operations that led to a change in the riparian landscape. The dynamic model is targeted on Monsoon floodplain vegetation, it is developed upon a custom developed geo-processing framework and supported by a standalone user interface. It simulates dynamics of floodplain vegetation communities based on different physical parameters. The general concept of the model is that a vegetation community will either undergo toward a maturation stage or will be destroyed (recycling or retrogression) if the magnitude of key physical parameters is greater than the threshold value for a specific community. The model has been calibrated using hydraulic data spanning the time period 1952–2007. The calibration results have been also used to investigate the impacts on the riparian vegetation given by dams operations. The findings of the research highlight that consecutive years of reduced maximum discharge allowed consistent vegetation colonization of riverine areas that were bare before the dam construction.

Keywords: Floodplain dynamic model; Monsoon floodplain vegetation; Dam operations; Long term assessment; Nakdong River

1. Introduction

Riverine ecosystems are among the most world's valuable and diverse ecosystems. However, despite their value, they are widely endangered by anthropogenic activities such diversions, dam operations and other regulation measures (Graf, 1999; Naiman et al., 2005; Nilsson et al., 2005; Poff et al., 1997; Tockner and Stanford, 2002). More in detail, dam operations alter the hydrological regime which is the leading

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force shaping the riparian ecosystems (Poff et al., 1997; Poff and Ward, 1989). Alterations include magnitude, frequency, timing, duration and rate of change of the hydrological regime (Poff et al., 1997). As floodplain vegetation is strongly related, dependent and adapted to hydrological regimes (Bendix and Hupp, 2000; Bornette and Amoros, 1996) their alteration leads to loss of ecological functionality of the riparian vegetation (Nilsson and Berggren, 2000). More in detail the negative impacts on the vegetation include the expansion of riparian forest due to the reduced discharge peaks (Azami et al., 2004), reduction of bare plots suitable for vegetation recruitment (Polzin and Rood, 2000) and ultimately the stabilization of the riparian landscape.

The Nakdong River (South Korea) is as well subject to damming. Particularly, this study focuses on the Nakdong section flowing downstream from two major dams impounding this river: Andong and Imha. These two massive works were respectively completed in the 1970s and in the 1990s. The study site was historically bare and it was as such even after the construction of the first dam (Andong). Once the second dam (Imha) begun its operations deep changes occurred in the landscape mosaic and river morphology. The bank zone which was once mainly occupied by sand has been progressively colonized by vegetation. Together with the spread of vegetation, there was a sediment and floods cut accompanied by bed sediment coarsening which are typical impacts of dam operating in Monsoon climate (Azami et al., 2004). The surveys from Azami et al. (2004), were based on statistical analysis of direct observations therefore focused on processes that already took place and no longer modifiable by changes in the dam operations pattern. In a sustainable water management perspective, these researches are extremely valuable contribution to the riparian ecosystems body of knowledge but somehow they are not sufficient for a complete assessment of the dam operations impacts because they describe a static picture. In this scope, the use of models represents a more suitable tool to support decisions inherent to river management and long term assessment of the riparian ecosystem ecological functionality (Turner et al., 1995).

Flow alterations are mutually influenced by both vegetation and morphodynamic processes (Bendix and Hupp, 2000; Edwards et al., 1999), these relationships show some degree of predictability and therefore can be at least partially replicated by simulation models (Perona et al., 2009). In the past decades, countless models have been implemented (Auble et al., 1994; Franz and Bazzaz, 1977; Pearlstine et al., 1985; Poiani and Johnson, 1993). Among these, the one implemented by Benjankar (2011) was specifically developed to investigate the ecological losses caused by dam operations. The presented paper authors implemented a model derived from Benjankar's (2011) original model. Derived model retained all the main features of the original one with the addition and modification of some attributes. The features of Benjankar's model which made of it an appropriate tool for decision support, are its capability of simulating the spatiotemporal variations of the floodplain vegetation composition producing visual results (raster maps) and tabular data. Benjankar's model evaluates the vegetation response to hydrology driven factors which are commonly found in most riparian ecosystem of the temperate climates (Hupp and Osterkamp, 1996). On the other hand, these leading forces were modeled based on their specific behavior in North American riparian ecosystems. Such custom implementation does not allow to apply the model tout court to the Nakdong riparian floodplain where the ecosystem behaves differently. The behavioral differences are given by the hydrographs pattern: in Northern America, the maximum discharges occur in the spring period which follows the snowmelt (Mahoney and Rood, 1998; Polzin and Rood, 2006). On the other hand, in Korea the maximum discharges are measured during summer and are due to the precipitations associated with the Wet Monsoon.

The presented research is part of the ECORIVER21 Research Program (Woo, 2010), promoted by the South Korean government to provide technical support for policies aimed to the enhancement of the environmental functions of rivers. In this paper is presented the adaptation of Benjankar's et al. (2011) dynamic vegetation model to the Nakdong riparian ecosystem. The research objectives were, at first the development of a more user friendly and domain specific application to apply Benjankar's model concept. In second instance, the objective encompassed the conceptual adaptation of the existing dynamic vegetation model to a typical Korean riparian ecosystem. The model thus re-implemented and conceptually adapted has been calibrated and tested to explore the Nakdong riparian ecosystem functioning in respect of dam operations. More in detail, the model has been used to investigate what were the effects of dam operations that brought the study site from being mainly bare to the current, widely vegetated, situation.

The model results have been analyzed focusing on three time frame periods based on the dam operations timeline and corresponding to three scenarios. Scenario 1: pre dams (1952–1976), scenario 2: post Andong dam (1976–1991) and scenario 3: post Imha dam (1992–2010). In scenario 1, pre dams, the Nakdong River was flowing free from dam regulation, the peak discharges were not mitigated or controlled by any dam and, according to historical aerial photographs (Fig. 1A) the riparian landscape was in its natural condition. In the time frame of scenario 2, post Andong, the river flow was regulated by the construction of Andong dam. In the last time frame, scenario 3, the Nakdong River discharge was heavily regulated by the combined effect of the operation Andong and Imha dams. The aerial photographs show for this scenario period (Fig. 1B) a deep change in the vegetation which established also in areas historically free from vegetation (Fig. 1A).

The interpretation of the three scenarios and the model adaptation represented the first step toward further studies on feasible river management strategies applicable to the Nakdong River.

2. Materials and methods

2.1. Study area

The investigated study area lies in the upper part of the Nakdong River (Fig. 2), the biggest river in South Korean. Its