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Evaluating the environmental flows of China's Wolonghu wetland and land use changes using a hydrological model, a water balance model, and remote sensing

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ABSTRACT

Environmental flows are critical to sustaining a variety of plant and animal communities in wetlands. However, evaluation of environmental flows is hampered by the problem of hydrological and ecological data shortage, especially in many developing countries such as China. Based on a hydrological model, a water balance model and remote sensing data, we assessed the environmental flows of China's Wolonghu wetland with limited data. The hydrological model provides input data for the water balance model of the wetland, and the remote sensing data can be used to assess land use changes. Integration of these two models with the remote sensing data revealed both the environmental flows of the Wolonghu wetland and the relationships between these environmental flows and land use changes. The results demonstrate that environmental flows have direct and indirect influences on the wetland ecosystem and should be linked to sustainable wetland management.

1. Introduction

Environmental flows refer to the water provided within a river, wetland, or coastal zone to maintain ecosystems and the benefits they provide to people. Wetland ecosystems rely on these environmental flows to maintain the flooding and drying cycles that are critical to sustaining a variety of plant and animal communities (Powell et al., 2008). Evaluation of these environmental flows is thus an important tool in management activities to protect wetlands.

Evaluation of environmental flows is a difficult task as it must incorporate highly coupled hydrological and ecological processes that interact in complex ways (Costelloe et al., 2003; Thompson et al., 2004; Overton, 2005). Complex environmental flow models, based on the differential equations used in ecology and hydrology, can more accurately model ecological and hydrological processes than simple models, but these models require comprehensive input data and complicated analytical techniques that make them unsuitable when there is insufficient input data or a lack of resources to obtain such data (Paul et al., 2000; Schneiderman et al., 2007). Thus more and more researchers have begun to employ simple models in the evaluation of environmental flows of wetlands. For example, a simple groundwater model based on MODFLOW was used to simulate groundwater discharge to floodplain wetlands in the upper and lower catchment with a timescale varying from 6 months to 25 years and with grid cell size of generally 1 km^2 (Grapes et al., 2006). Powell et al. (2008) developed a parsimonious model for assessing ecologically significant flood dynamics of floodplain wetlands, due to lack of available data for model development and calibration using conventional modelling approaches.

The application of complex models in most of China's wetlands is especially limited due to lack of access to the necessary meteorological and hydrological data. In addition, such models require an understanding of land use patterns and changes in the areas that affect environmental flows within and into the wetland. The distribution and composition of this land use reflect histories of both fluvial disturbance from floods and the non-fluvial disturbance regimes in adjacent upland areas (Reid and Quinn, 2004). Moreover, the structure and floristic composition of each land use type are influenced by local hydrological regimes (Kingsford, 2000; Quinn and Hanna, 2003). Simpler hydrological models, such as those based on the curve number method, can be used to assess environmental flows within and into wetlands because they require less input data. In addition, land use data in and around the wetlands can be provided using remote sensing data, such as the Landsat TM data (Shaikh et al., 2001; Toyra and Pietroniro, 2005), thereby providing a more comprehensive view of the wetland.

In this study, we develop a water balance model, with input provided by a hydrological model, and combine it with remote sensing data to permit spatial and temporal analyses of changes in wetland vegetation. Then we apply the results in the development of a water balance model which is capable of assisting environmen-

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tal flow management in China's Wolonghu wetland. The key data required for the model include inflows, outflows, water levels, and the area inundated by water.

2. Study site and data sources

The Wolonghu wetland, located between 123°09′E and 123°20′E longitude and 42°40′N and 42°47′N latitude, covers an area of 71.6 km^2, is the largest wetland in the Liao River basin. The Liao River is the largest river in Liaoning Province, Northeast China (Fig. 1). The East Malian River and West Malian River, with a catchment area of 1600 km^2, join the Wolonghu wetland and then flow into the Liao River. Both rivers originate in Inner Mongolia. The elevations of the wetland range from 85 to 95 m. The wetland holds water to an average depth of 2 m. In the East Malian River and West Malian River basin, the average annual precipitation is 450 mm and the average annual runoff is 64×10^6 m^3. The circumjacent land use is dominated by reed communities. The Wolonghu wetland is the most important wetland in the Liao River basin for migratory birds such as the white stork (*Ciconia boyciana*), black stork (*Ciconia nigra*), hooded crane (*Grus monacha*), red-crowned crane (*Grus japonensis*), and Siberian crane (*Grus leucogeranus*).

Available data for the Wolonghu wetland are limited because there is only one station that monitors water levels. In the absence of more detailed monitoring, a hydrological model combined with a water balance model and remote sensing data can make better use of the available data to inform management in our study. To assist in the development of the model, we obtained monthly water depth data from 1972 to 2006 from the Liao River Water Resources Committee. Monthly meteorological data from areas around the Wolonghu wetland from 1972 to 2006 were obtained from the National Meteorological Service. To study land use changes, we obtained Landsat TM images for July 1988, August 1991, July 1997, September 2003, and September 2006.

3. Methods

We combined a hydrological model with a water balance model and remote sensing data to evaluate ecosystem responses to the changing environmental flows of the Wolonghu wetland. The Soil Conservation Service (SCS) curve number method was employed to model the hydrological cycle of the wetland and to provide hydrological data as inputs for the water balance model. Land use was classified using version 8.0 of the ERDAS IMAGINE software (ERDAS Inc., Norcross, GA) to reveal ecosystem changes due to changes in the hydrological cycle.

3.1. Hydrological model

The SCS curve number method was first developed by the United States Department of Agriculture in 1954 to transform rainfall data into surface runoff predictions. The curve number method is well established in hydrology, agriculture, and environmental engineering, and was used in the present study because it has been widely used in numerous other models, including the Agricultural Non-Point Source Pollution (AGNPS) model for single events, the

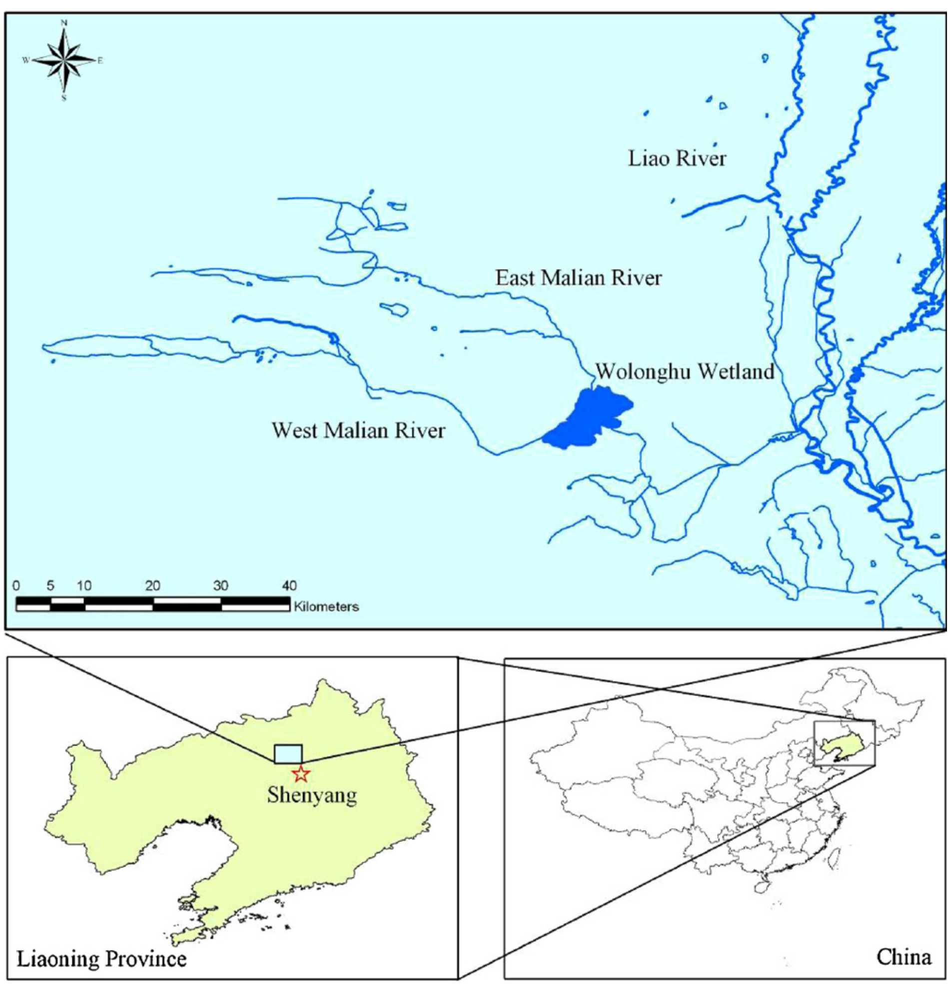

Fig. 1. Location of the Wolonghu wetland.