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Flood management of Dongting Lake after operation of Three Gorges Dam

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Abstract

Full operation of the Three Gorges Dam (TGD) reduces flood risk of the middle and lower parts of the Yangtze River Basin. However, Dongting Lake, which is located in the Yangtze River Basin, is still at high risk for potentially severe flooding in the future. The effects of the TGD on flood processes were investigated using a hydrodynamic model. The 1998 and 2010 flood events before and after the operation of the TGD, respectively, were analyzed. The numerical results show that the operation of the TGD changes flood processes, including the timing and magnitude of flood peaks in Dongting Lake. The TGD can effectively reduce the flood level in Dongting Lake, which is mainly caused by the flood water from the upper reach of the Yangtze River. This is not the case, however, for floods mainly induced by flood water from four main rivers in the catchment. In view of this, a comprehensive strategy for flood management in Dongting Lake is required. Non-engineering measures, such as warning systems and combined operation of the TGD and other reservoirs in the catchment, as well as traditional engineering measures, should be further improved. Meanwhile, a sustainable philosophy for flood control, including natural flood management and lake restoration, is recommended to reduce the flood risk.

Keywords: Three Gorges Dam; Flood control; Water level; Hydrodynamic model; Dongting Lake

1. Introduction

Flooding of Dongting Lake has been one of the most common problems in the Yangtze River Basin. In past decades, floods occurred frequently, once every four years on average. Flood disasters have recently become even more frequent and caused more serious losses (Yin et al., 2007). Large floods occurred almost every year in the 1990s and flood levels repeatedly exceeded the previously recorded highest flood level of 1954. For example, the 1996 flood, mainly caused by local rainfall in the catchment, forced about 1.02 million people to move to the embankment. In 1998, despite the fact that the rainfall did not reach historical highs, the recorded water levels of Dongting Lake were much higher than the historical maximum (Zong and Chen, 2000). According to a report published in the *People's Daily* on August 26, 1998, 223 million people were affected by floods, and about 4970000 houses were destroyed.

Large-scale reclamation in the lake area, lake deposition, and other factors have directly led to a rapid reduction in the surface area and storage capacity of Dongting Lake. They have also caused the weakening of flood diversion and storage functions of Dongting Lake (Du et al., 2001), resulting in a significant rise of the flood levels corresponding to certain discharge amounts. Thus, flood disasters have become more frequent and serious. The highest flood level recorded at the

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Chenglingji Station (the sole outlet of Dongting Lake) was continually exceeded throughout the 1990s, rising from 34.55 m in 1954 to 35.31 m in 1996 and then to 35.94 m in 1998. However, the maximum discharge in 1998 at the Luoshan Station (about 40 km downstream from the outlet of Dongting Lake) was 68600 m^3/s, significantly less than the maximum discharge of 78800 m^3/s in 1954.

Located at the boundary between the upper and middle reaches of the Yangtze River, the Three Gorges Dam (TGD), is expected to significantly help control the floods of the middle part of the Yangtze River Basin, including Dongting Lake. The TGD was launched in 1993, beginning with the pilot impoundment in June 2003, and has been fully operated since 2010, when a normal water level of 175 m above the mean sea level was reached. Various investigations have confirmed that the flood risk status in the middle and lower reaches of the Yangtze River has been improved significantly (Fang et al., 2012; Hu et al., 2015; Lai et al., 2013a; Li et al., 2009; Zhou et al., 2009). Indeed, no disastrous flood has occurred since the beginning of operation of the TGD in 2003. On the contrary, severe seasonal droughts in Dongting Lake have attracted most attention (Huang et al., 2014; Lai et al., 2014).

In spite of this, climate change studies have shown that the Yangtze River Basin is likely to face more serious flood disasters, because of an upward trend in total rainfall (Hartmann et al., 2012; Zhang et al., 2008) and an increase in the frequency of extreme rainfall events (Su et al., 2006) in the middle and lower parts of the basin over recent decades. Due to the potential for large floods caused by extreme weather in the future, the safety of Dongting Lake is far from assured.

For this complex river-lake system, hydrodynamic models are preferred when investigating flood processes. There have been some interesting studies that have focused on large water systems. Paz et al. (2010) modeled large-scale hydrodynamics of a complex river network and floodplains. Paiva et al. (2011) simulated river flows of the Amazon River using a large-scale hydrological and hydrodynamic model. D'Alpaos and Defina (2007) developed a full hydrodynamic model for many connected lagoons. For the large river-lake system in the middle part of the Yangtze River Basin with strong river-lake interactions, some local one-dimensional (1D) and two-dimensional (2D) hydrodynamic models have been used to investigate the river flow and sediment transport. Lai et al. (2013b) developed a large-scale hydrodynamic model covering all main rivers and open lakes in the middle part of the Yangtze River Basin. Compared to observed results, these hydrodynamic models can output flood information over different spatial and temporal scales. They may help us to identify some key points that cannot be derived from observations alone, for improving our flood management policy. For example, Jiang et al. (2007) suggested a new lake restoration strategy based on the models' findings on the flood response to the lake restoration from polders.

In order to understand possible flooding scenarios of Dongting Lake and improve flood management after the operation of the TGD, the effects of the operation of the TGD on typical floods were quantified. Flood management is also described below, with the aim of reducing the potential flood risk.

2. Data and methods

2.1. Study area

Dongting Lake (at latitudes 28°44′N to 29°35′N and longitudes 111°53′E to 113°5′E (Fig. 1)) is located in northeastern Hunan Province, in central China, and on the south bank of the mainstream of the Yangtze River. It is the second largest freshwater lake in China and is naturally connected to the mainstream of the middle reaches of the Yangtze River. The surface area of Dongting Lake was 6000 km^2 in 1825. Due to long-term siltation and land reclamation, Dongting Lake has been divided into numerous small lakes and three large ones (East, West, and South Dongting lakes), which connect to the Yangtze River. To date, the surface area of Dongting Lake has already decreased to about 2700 km^2 (Dou and Jiang, 2000).

The Dongting Lake catchment area is 257000 km^2. There are four main rivers in the catchment (excluding the area whose water flows directly into the Yangtze River, the same hereafter): the Xiangjiang, Zishui, Yuanjiang, and Lishui rivers, which flow directly into the lake. In addition, some of water of the Yangtze River also flows into the lake through the Sankou distributary channels. The catchment has highly complex flow regimes featuring strong river-lake interactions (Yin et al., 2007). Dongting Lake receives water from the upper Jingjiang reach of the Yangtze River. The water in Dongting Lake finally flows into the lower Jingjiang reach of the Yangtze River at the Chenglingji Station and discharges downstream.

The water in Dongting Lake mainly comes from surface runoff and direct rainfall on the lake surface. The Dongting Lake catchment begins to enter the rainy season in April and the rainfall reaches its maximum in June. Then, the rainy area moves to the upper part of the Yangtze River Basin in July and flood water flowing into the lake from upstream increases significantly. The rainy season may continue until the end of September. The flow regime of Dongting Lake maintains the same temporal pattern as the rainfall regime. The flood season is from April to September. In general, flood water comes mainly from the catchment from April to June and from water diversion of the upper reaches of the Yangtze River from July to September. The annual runoff from Dongting Lake to the Yangtze River is 278.6 km^3, of which 92.3 km^3 is received from the Yangtze River through the inlets (Dou and Jiang, 2000). Influenced by the monsoon, the lake shows a significant seasonal change in its flow regime. The lake water level fluctuates dramatically throughout a year, up to 12.9 m (Dou and Jiang, 2000). The water surface area also varies with the fluctuation of the water level from thousands of square kilometers in the flood season to only a few hundred square kilometers in the dry season.

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