Journal of Marine Systems 88 (2011) 252–266

Contents lists available at ScienceDirect

Journal of Marine Systems

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

Modeling the mass flux budgets of water and suspended sediments for the river network and estuary in the Pearl River Delta, China

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ARTICLE INFO

Article history:
Received 28 August 2010
Received in revised form 27 April 2011
Accepted 5 May 2011
Available online 15 May 2011

Keywords:
Water flow
Suspended sediments
Flux
Deposition and resuspension
Estuarine dynamics
Mathematical models

ABSTRACT

A coupled physical and sediment transport model was used to study the mass flux budgets of water and suspended sediments in the Pearl River Delta (PRD). The coupled model incorporates the Pearl River network, the Pearl River Estuary (PRE) and adjacent coastal waters in one overall modeling system. The results indicate that the river network and the PRE both have pronounced temporal and spatial variability in water and sediment fluxes, in hydrodynamic features and in sediment depositional patterns. In the river network, the riverine fluxes of water and suspended sediments are dominated by the West River, and those that are exported to the PRE (defined as the estuarine fluxes) are primarily contributed by Modaomen. The river outlets are highly responsive to the main tributaries in terms of water and sediment fluxes, revealing a close coupling between the upstream and the downstream boundaries. Most of the annual riverine and estuarine fluxes occur in the wet season, approximately 74% of the water flux and riverine and estuarine fluxes of suspended sediments of 94% and 87%, respectively. Although the water and sediment transport is dominated by river discharge, the tides are also an important factor, especially in regulating the structures of seasonal deposits in the river network (deposition in the wet season and erosion in the dry season). In the PRE, various types of physical forcing, including river discharge, monsoon winds, tides, coastal currents and the gravitational circulation associated with a density gradient, operate in concert to control the water and sediment transport in the estuary. Most of the oceanic fluxes of water and suspended sediments entering the South China Sea take place in the dry season and are primarily conveyed by strong western coastal currents. The PRE is a sedimentary system characterized by intricate depositional structures in space and time. Several depositional patterns and the associated driving mechanisms were identified. A fan-shaped deposition zone, the most intense deposition belt in the PRE, was found in the outer Modaomen Bay, where hypoxia has been reported. This work provides a basis for subsequent water quality applications in the PRD, including studies of hypoxia, eutrophication and maximum turbidity.

1. Introduction

In estuaries, suspended sediments play an important role in biogeochemical cycles, primary production of phytoplankton, pollutant transport and formation of a turbidity maximum, and they provide a critical link between the water column and the bottom sediments (Turner and Millward, 2002). Understanding the estuarine dynamics of suspended sediments, especially in terms of their mass fluxes and transport mechanisms, is crucial in interpreting a number of environmental issues (Ji, 2007; Liu et al., 2002), such as degradation of water quality, eutrophication and sediment bed siltation and erosion. With an awareness of these problems, many studies (e.g., Blass et al., 2007; Hu et al., 2008; Liu et al., 2002; Wu et al., 1999) have been initiated in recent years, applying numerical models to describe estuarine sediment transport processes. The results from these studies indicate that numerical modeling is an effective approach for quantifying suspended sediment dynamics. Numerical models are likely to provide better estimates of the sediment fluxes through estuarine systems when compared to estimates using direct observations because errors associated with under-sampling can be avoided in flux calculations using model results (Jay et al., 1997). To achieve accurate predictions of sediment transport processes, it is critical to accurately represent hydrodynamic processes, the most important mechanisms governing suspended sediment transport (Ji, 2007; Liu et al., 2002).

Our area of interest in this study is the Pearl River Delta (PRD, see Fig. 1), a dynamically complex estuarine system located in the northern continental shelf of the South China Sea (SCS). It consists of a river network (called the Pearl River network) and an estuary (called the Pearl River Estuary). These two portions of the PRD are connected by eight river outlets and are intimately interrelated.

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0924-7963/$ – see front matter
doi:10.1016/j.jmarsys.2011.05.002

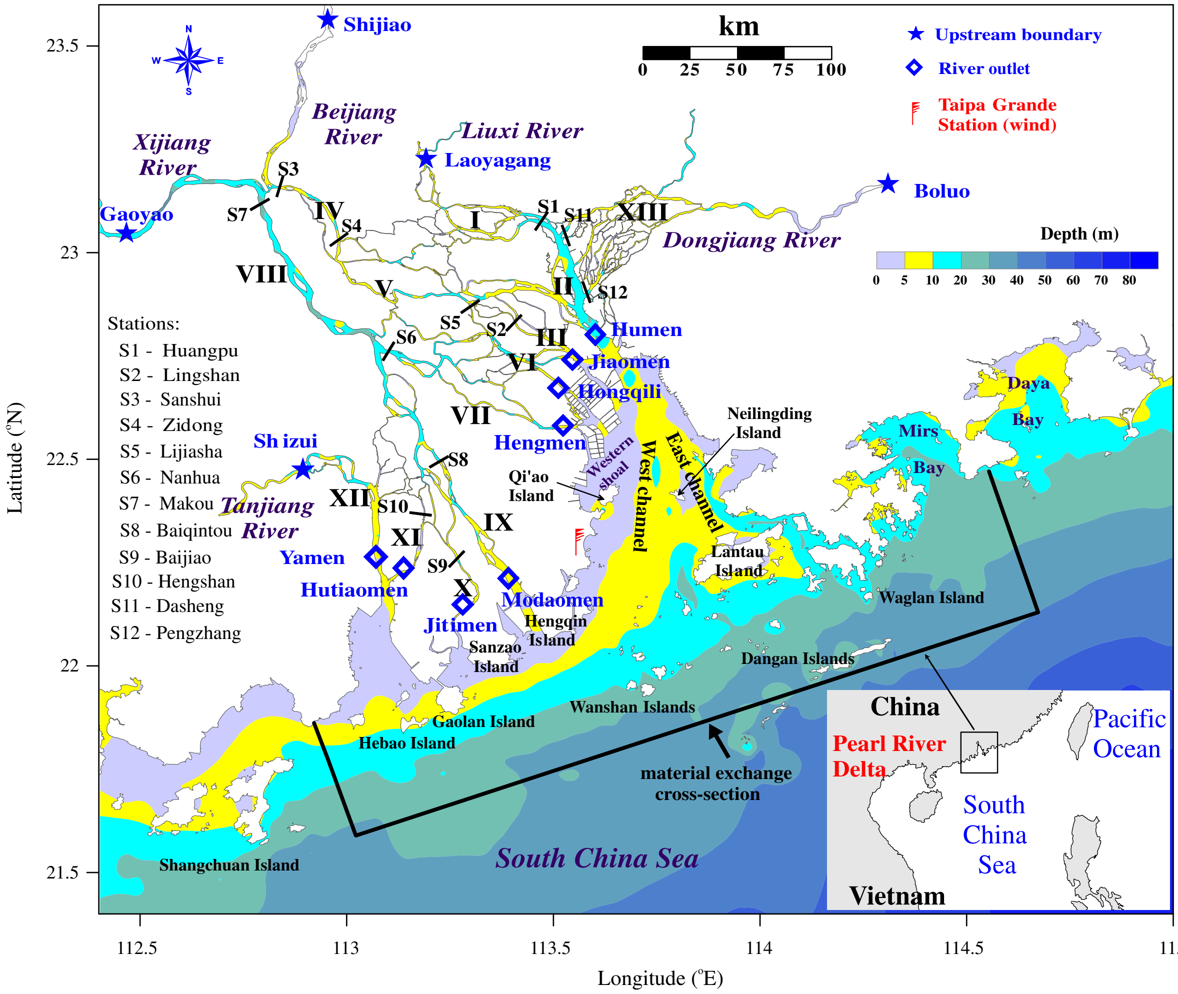

Fig. 1. Map of the Pearl River Delta with its river network system and estuarine bays. To estimate regional sediment deposition rates, the river network is divided into 13 subareas, including the Zhujiang mainstream (I: Laoyagang—S1), the Humen channel (II: S1—Humen), the Jiaomen channel (III: S2—Jiaomen), the North River mainstream (IV: S3–S4), the Shunde channel (V: S4–S5), the Hongqili channel (VI: S5—Hongqili), the Hengmen channel (VII: S6—Hengmen), the West River mainstream (VIII: S7—S8), the Modaomen channel (IX: S8—Modaomen), the Jitimen channel (X: S9—Jitimen); the Hutiaomen channel (XI: S10—Hutiaomen), the Tanjiang-Yamen channel (XII: Shizui—Yamen) and the East River network (XIII: Boluo—S11–S12). Note that the 3D model domain extends further than the area shown here and can be found in Fig. 4a of Hu and Li (2009).

They have distinct features in their dynamics, morphology, evolution and environmental issues (Wu et al., 2007). The Pearl River network is the largest and most complicated tidal river network system in China. It comprises five main tributaries of the Pearl River, including the West River, North River, East River, Liuxi River and Tanjiang River. These rivers bifurcate repeatedly after entering the PRD and form an intricately interlaced network of narrow river channels (Hu and Li, 2009; Wu et al., 2007), which exhibits various types of water flow states under the combined effects of tidal rise and freshwater discharge. The mean suspended sediment concentration in the river network is about 0.284 kg m^{-3}, less than other major rivers in China (Luo et al., 2002). The mean annual loads of water and suspended sediments from the five main tributaries have strong seasonal variations, and they average (from 1959 to 1979) 3260×10^8 m^3 and 8872×10^4 t, respectively (Luo et al., 2002). These loads pass through the river network, flow into the Pearl River Estuary (PRE) through the eight river outlets and are eventually transported to the SCS. The river network is the largest contributor of water and suspended sediments to the PRE (Hu and Li, 2009), which is the second largest contributor of water and suspended sediments to the SCS (Zhang et al., 2007). Therefore, the transport and mass fluxes of water and suspended sediments in the river network have substantial influences on the evolution and environments of both the PRE and the SCS.

The PRE is a broad bell-shape estuary with eight river outlets on its western bank and two deep channels (namely, the East Channel and West Channel, see Fig. 1 for their locations) extending from the head of the estuary to its coastal waters. Its tidal range is about 2 m (Dong et al., 2004). The tides propagate from offshore towards the estuary with a gradual increase in the tidal range, which reaches a maximum near the river outlets (Mao et al., 2004). The PRE is subject to the influence of alternating monsoons, with southwesterly winds prevailing in the summer and northeasterly winds prevailing in the winter. As affected by the river network, the PRE exhibits clear seasonal variability in terms of river discharge, suspended sediment concentration and sediment flux (Luo et al., 2002; Wong et al., 2003a; Wong et al., 2003b). In general, the estuarine circulation and water properties in the PRE are controlled by various forcing mechanisms, including river discharge, tides, monsoon winds, coastal currents and buoyancy forcing associated with the mixing of freshwater and saline water (Dong et al., 2004; Wong et al., 2003a; Wong et al., 2003b; Zu and Gan, 2007). Suspended sediments in the PRE are comprised of fine-grained silt and clay, with a median particle diameter of about 8 μm (Chen et al., 2005). A turbidity maximum was also observed in this region. Its formation was the result of the complicated hydrodynamic and sediment transport processes (Wai et al., 2004).

There have been many numerical model studies on the hydrodynamic processes in the PRD, using 1D models for the river