Available online at www.sciencedirect.com
ScienceDirect
Coastal Engineering 54 (2007) 297–320
Coastal Engineering
An International Journal for Coastal, Harbour and Offshore Engineers
www.elsevier.com/locate/coastaleng

Numerical modelling of water transport processes in partially-connected tidal basins

Agnieszka Herman *

Coastal Research Station, Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency, An der Mühle 5, 26548 Norderney, Germany

Received 14 March 2006; accepted 11 October 2006
Available online 30 November 2006

Abstract

In the paper two types of numerical models – a lumped-parameter model and a high-resolution two-dimensional hydrodynamic model – are used to analyse the response of a system of partially-connected tidal basins to inhomogeneous open sea forcing. The equations of the lumped-parameter model, suitable for an arbitrary number of basins with sloping walls, are formulated based on one-dimensional continuity and momentum equations. Numerical solutions to the equations are thoroughly examined, showing the influence of inhomogeneous open sea forcing and of geometrical parameters of the basins on the tidal range and the water transport through the system, with particular emphasis given to inter-basin water exchange and cumulative water transport through basins boundaries. The results of the lumped-parameter model simulations for the tidal basins of the German Wadden Sea are successfully compared with the results of calculations with the two-dimensional hydrodynamic model, which is used to investigate in more detail circulation patterns and the influence of specific local features of inlet bathymetry on the hydrodynamic processes in the study area. The influence of wind on the basins response is discussed as well.

Keywords: Tidal inlets; Inter-basin water exchange; Lumped-parameter model; Delft3D; Wadden Sea

1. Introduction

Understanding of hydrodynamic processes in tidal coastal environments has long been recognized as very important not only from a scientific point of view, but also for various aspects of human activities, including design of coastal protection structures, navigation or environmental risk assessment. However, although much effort has been put into studying them, tidally shaped coastal zones built of islands, tidal flats and channels and being a product of complex interactions between hydro- and morphodynamic processes, remain a very challenging subject of theoretical, numerical and experimental investigations. If numerical modelling of the response of the tidal basins to open sea forcing is considered, two main approaches can be identified. The first group constitute the so-called lumped-parameter models, based on one-dimensional continuity and momentum equations applied to (a system of) basins and channels parameterized by a few easy-to-handle parameters like volume, surface area, mean water depth etc. Thus, a lumped-parameter model provides means to calculate – with a simple numerical scheme or in some cases analytically – the overall tidal characteristics like volume fluxes through inlets or the tidal range. Apart from their simplicity, the advantage of lumped-parameter models is that one can easily vary the model parameters to study their influence on the behaviour of the system and to formulate general 'rules' describing relations between basins' geometry and their response to the forcing. Good examples are the works of van de Kreeke (1988, 1990), DiLorenzo (1988), Ridderinkhof (1988), Friedrichs and Madsen (1992) and Maas (1997), to name just a few.

The second approach, developing rapidly in recent years, is based on state-of-the-art two- or three-dimensional hydrodynamic models, in which complicated bathymetry and shape of the water bodies, influence of meteorological conditions, water density gradients and many other factors can be taken into

* Present address: Institute of Oceanography, University of Gdansk, Pilsudskiego 46, 81-378 Gdynia, Poland. Tel.: +48 58 523 68 79.
E-mail address: herman@ocean.univ.gda.pl.

0378-3839/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.coastaleng.2006.10.003

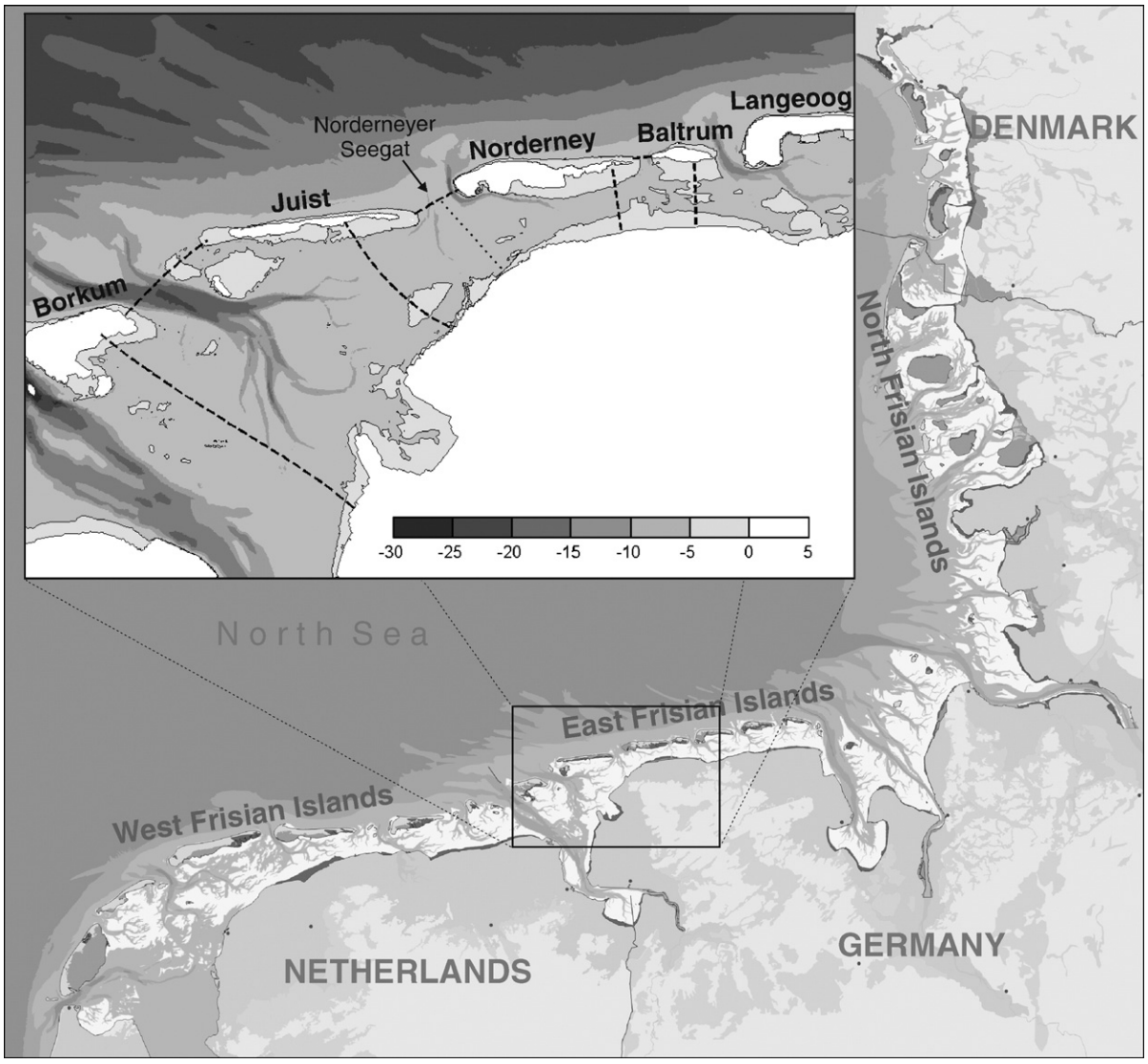

Fig. 1. Location and bottom topography (in meters) of the study area. The dashed lines mark the boundaries of the sub-basins of the Wadden Sea, the dotted line — approximate position of a division line through the basin of Norderney suggested by Stanev et al. (2003a,b) (detailed description see text).

account with spatial and temporal resolution limited practically only by the computer resources available. Although in many cases modern numerical models provide information impossible to gain by other means, the amount of detail that that information contains makes the interpretation of the results difficult and leads to the need of reducing it e.g. to certain statistical parameters. Examples of advanced numerical modelling of tidal hydrodynamics can be found e.g. in Hench and Luettich (2003), Stanev et al. (2003a,b).

In the present work both approaches are applied to study water transport processes in a system of tidal basins separated from the open sea by a chain of islands, with emphasis on exchange mechanisms through watersheds between the neighbouring basins and on cumulative water transport through the whole system. Because both phenomena are extremely difficult and expensive to investigate experimentally through direct field measurements (especially over longer periods of time), simulations with reliable models verified against other, more easily obtainable data (water level and current measurements at chosen locations or along profiles etc.) are often the only way to understand them. Although the inter-basin exchange in many systems is known to play an important role and influences, among other things, sediment budget and dispersion of suspended particles, organisms and contaminants, it is often underestimated, like e.g. in a study by Stanev et al. (2003b), who treat the basins of the German Wadden Sea as unconnected water bodies.

In the first part of the paper, the equations of a lumped-parameter model for an arbitrary number N of partially-connected tidal basins are developed and analysed. The model enables to take into account effects of variable basin surface areas and variable cross-sectional areas of the channels connecting the basins with an open sea. Unlike most of the earlier studies that concentrated on the dynamics of single basins with multiple inlets or disconnected basins, here the