The Application of Numerical Modelling in Managing Our Water Environment

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Abstract

For over a decade, the Environmental Protection Department (EPD) of Hong Kong has been using numerical models to assess the impact of human activities on the quality of coastal waters. An example, using Delft3D as the modelling tool, is presented in this talk to illustrate the key role played by numerical models in the prediction of water quality in the aquatic environment. It demonstrates how model calculation was used to estimate the cumulative impact of coastal developments in Hong Kong for over 2 decades. With rapid advances in computer technology and continual development of modelling techniques, greater accuracy and wider application could be achieved and the utilization of numerical models as a tool for the assessment of environmental impact could be further promoted.

1. Introduction

Since 1987, the Hong Kong Government has been using water quality and hydrodynamic mathematical models to examine impacts of human activities and coastal developments on Hong Kong's marine waters. The capability of these numerical models has significantly improved over the past some 20 years.

This paper aims to introduce the current numerical tool used by the EPD for water quality assessment. An application example is used to illustrate how the tool was used to assess the cumulative impacts of coastal developments relevant to the management of the coastal waters of Hong Kong.

2. The Model

The first Water quality and Hydraulic Models of the EPD, known as the WAHMO model and developed for formulating a territorial development strategy in 1987, incorporated the state-of-the-art techniques at the time of development. It adopted the finite difference technique, a square grid in the horizontal space of resolution up to 250m. However, the vertical dimension was limited to 2 layers, which could not satisfactorily reproduce the density stratifications observed particularly in the western part of the Hong Kong waters in the wet season. Simulation periods normally covered a typical diurnal tidal cycle for the spring and neap tides in the dry and wet seasons. As technology develops and computer capability improves, these models gradually became less effective when compared with the more advanced models available in the market.

In 1996, the Hong Kong government commenced an exercise to upgrade its water quality and hydrodynamic models. A number of commercial models were reviewed, and various aspects had been considered before reaching the final decision on the choice of model, i.e., the Delft3D modelling suite. These aspects included scientific basis of the models and their numerical schemes; adequacy of parameters that were simulated; availability of pre-processing and post-processing tools; technical support; performance of the models during demonstration, trial runs and previous applications; model runtime; cost; and proposed staff resources for the assignment and their experience.

The selected Delft3D system is a modular modelling system developed by the WL| Delft Hydraulics, an independent research institute and specialist consultant based in the Netherlands. It adopts a curvilinear, boundary fitted orthogonal grid that has an advantage of a better representation of complex coastline configuration. Comparing to the traditional rectilinear grid arrangement, the number of grid points to cover the same model domain can be reduced while maintaining a high resolution for the area of interest. A multi-layer sigma co-ordinate transformation is applied in the vertical direction, resulting in a constant number of vertical layers over the whole computation domain while maintaining a smooth representation of the bottom topography.

The software suite comprises basic modules of Delft3D-FLOW, Delft3D-WAQ, Delft3D-PART and Delft3D-WAVE for modelling of tidal flows, water quality, particle tracking and waves respectively. The Delft3D-FLOW model can simulate water density and temperature that are important parameters for predicting density gradients in estuarine waters like those in the Pearl River Estuary. The Delft3D-WAQ model is based on the 3-dimensional advection-diffusion equations, together with an extensive water quality library of inter-related source and sink terms to represent water quality processes. Typical applications have 30 state variables to represent different substances in water and in bottom sediment, and these substances include salinity, temperature, oxygen, nutrients (nitrogen, phosphorus, silicon), phytoplankton, biochemical oxygen demand, suspended solids and *E. coli*.

3. Application example of the model in managing our water environment

An example is used here to illustrate how EPD uses the model to manage our water environment.

Example: Cumulative Water Quality and Hydrological Effect of Coastal Developments

Hong Kong SAR has been well known for its geographical location and deep harbour, which form an important gateway to the Mainland and is one of the busiest ports in the world. However, due to Hong Kong's mountainous landscape with limited lowland for development, reclamations along the coastal region were necessary to cope with the rapid development and increasing infra-structural needs. While environmental assessments had been conducted to ascertain the acceptability of individual reclamation projects to the marine environment, a question arose as to whether these developments, when taken together, would pose any insurmountable threat to the marine environment. In 1997, the EPD therefore commissioned this study to assess the cumulative effects of coastal developments on the marine environment (Hyder Consulting, 2000).

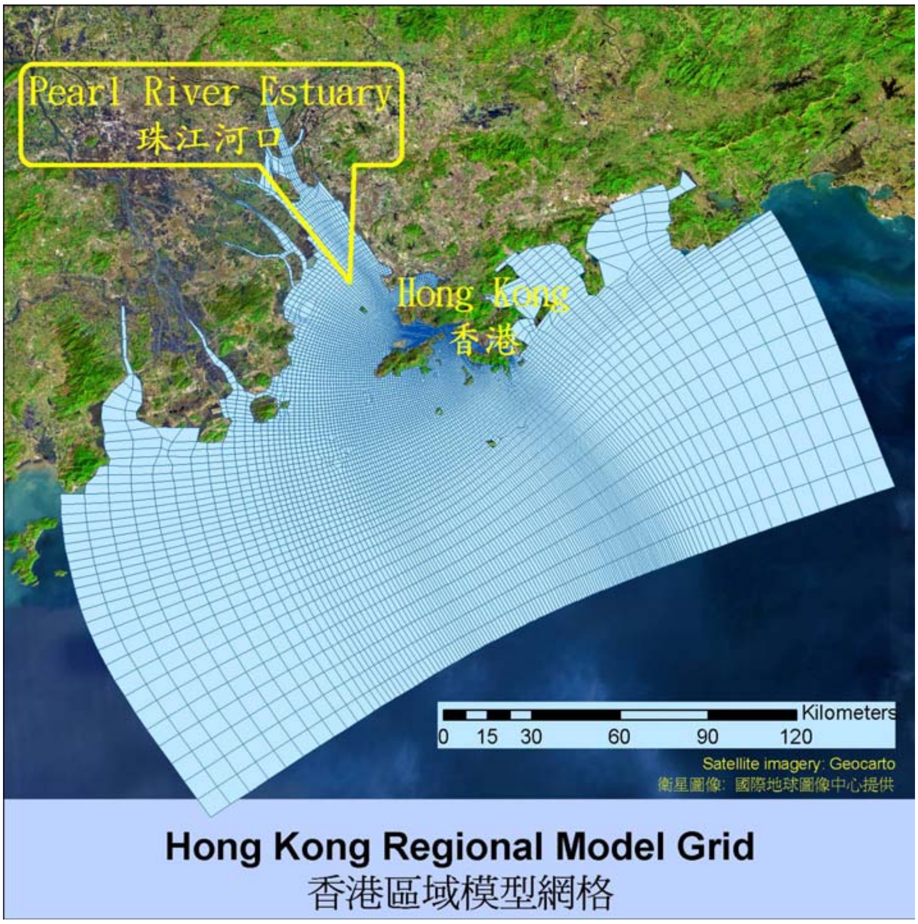

Figure 1 Grid Layout of the Hong Kong Regional Model

To form an accurate view on the cumulative hydrodynamic and water quality effects of coastal developments in different time horizons, a regional model was set up based on the calibrated and verified Delft3D model in 1996 (Ng *et al.*, 1998), and was further improved using the additional field data collected under the study (see Fig. 1 for model grid layout).

Annual simulations were conducted for six time horizons, three of which covered the historical years between 1987 and 1997, while the others were future scenarios from 2002 to 2012. Three main factors governing the water quality of Hong Kong were considered, which included (i) coastline configuration and seabed profile, (ii) local pollution sources and (iii) background pollution from other coastal waters. In order to isolate the relative significance of these factors on the overall water quality, a set of simulations was carried out in which only one factor was allowed to change at a time (Fig. 2). By comparing the results of the simulations with different combinations of inputs, the sensitivity of water quality due to changes in the governing factors was then determined.

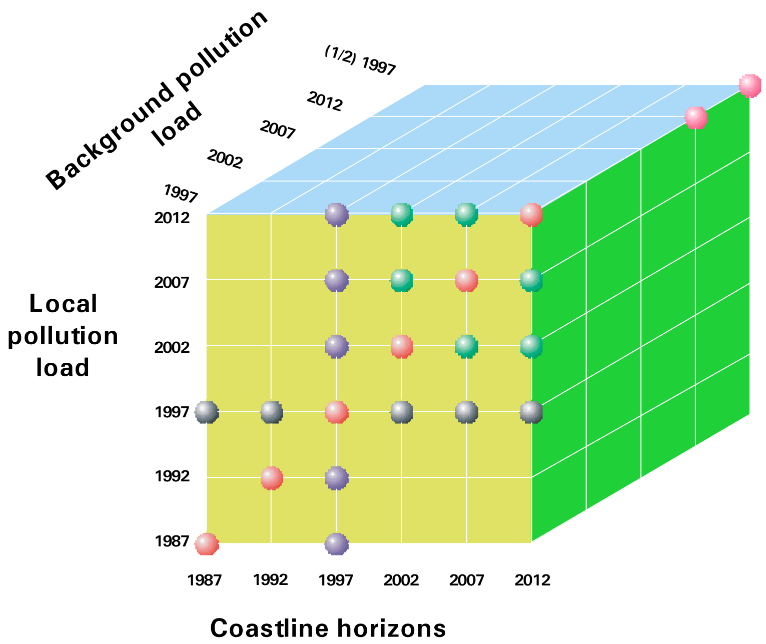

Figure 2 Sensitivity test scenarios for assessment of cumulative effects of coastal developments.

Results suggested that the coastal developments over the 25-year period would only have relatively localised effects on the water quality due to redistribution of flood and ebb flows across the major flow channels in Hong Kong (Table 1). The total flushing of the Hong Kong harbour system, between Ma Wan, Victoria Harbour, Lamma Island and Cheung Chau would remain largely unchanged.

% Change in Flow	Season			
	Wet		Dry	
	Flood	Ebb	Flood	Ebb
Urmston Road	-16	-16	-15	-16
East Ma Wan Channel	-7	-9	-5	-10
Kap Shui Mun	-6	-12	-5	-8
Rambler Channel	0	-7	-2	-4
Victoria Harbour	-11	-7	-11	-11
East Lamma Channel	0	-2	+4	-1
West Lamma Channel	-8	-10	-10	-10
Adamasta Channel	-20	-13	-22	-13

Table 1 Change in Flood and Ebb Flows through Main Channels in the Dry and Wet Seasons from 1987 to 2012.

On the other hand, gradual improvements in the coastal water quality were predicted between 1997 and 2012, and were mainly attributable to pollution load reduction schemes, such as the Harbour Area Treatment Scheme (previously known as the Strategic Sewage Disposal Scheme) and the implementation of the various Sewerage Master Plans in Hong Kong.

In this example, the numerical model had proven itself as a cost-effective tool in providing a better understanding on the effect of coastal developments on the water quality of Hong Kong. Through the sensitivity tests, the model had also helped to identify pollution loading as the predominant factor affecting the coastal water quality. This piece of information had enabled the Hong Kong SAR Government to focus its effort on the key factors for the long-term management of the marine waters of Hong Kong.

4. Conclusions

This paper gives a brief introduction of the water quality and hydrodynamic modelling system currently used by the EPD to assess human impacts on the marine environment. An example is used to illustrate its application in managing our waters.

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References

Delft Hydraulics, Origin & Hyder Consulting Limited (1998). *Agreement CE 48/96, Upgrading of the Water Quality and Hydraulic Mathematical Models, Executive Summary*.

Environmental Protection Department (1998). *Agreement CE 17/95, Deep Bay Water Quality Regional Control Strategy Study, Executive Summary.*

Hyder Consulting & Maunsell Environmental Management Consultants Limited (2000). *Agreement CE 42/97, Update on Cumulative Water Quality and Hydrological Effect of Coastal Developments and Upgrading of assessment Tool, Executive Summary*.

Ng. A.K.M, Roelfzema, A., Hulsen, L.J.M. (1998). "*3-dimensional Water Quality and Hydrodynamic Modelling in Hong Kong. I. Concepts and Model Set-up*", Proc. of the 2nd Int. Symp. on Environmental Hydraulics, p 31-36.