Environmental Modelling & Software 26 (2011) 1685–1695

Contents lists available at ScienceDirect

Environmental Modelling & Software

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

Application of a coastal modelling code in fluvial environments

I.M. Hartanto [a], L. Beevers [a], I. Popescu [a,*], N.G. Wright [b]

[a] UNESCO-IHE Institute for Water Education, Hydroinformatics and Knowledge Management, P.O. Box 3015, 2601 DA, Delft, The Netherlands
[b] University of Leeds, Leeds LS2 9JT, United Kingdom

ARTICLE INFO

Article history:
Received 27 August 2010
Received in revised form
17 January 2011
Accepted 3 May 2011
Available online 31 July 2011

Keywords:
Numerical model
River system
XBeach
Shallow water equations
Open software

ABSTRACT

XBeach is an open source, freely available two dimensional code, developed to solve hydrodynamic and morphological processes in the coastal environment. In this paper the code is applied to ten different test cases specific to hydraulic problems encountered in the fluvial environment, with the purpose of proving the capability of XBeach in rivers. Results show that the performance of XBeach is acceptable, comparing well to other commercially available codes specifically developed for fluvial modelling. Some advantages and deficiencies of the codes are identified and recommendations for adaptation into the fluvial environment are made.

Software Availability

Name of software: XBeach
Developers: It is a public-domain model that has been developed with funding and support by the US Army Corps of Engineers, by a consortium of UNESCO-IHE, Deltares (Delft Hydraulics), Delft University of Technology and the University of Miami
Contact address: UNESCO-IHE Institute for Water Education, Westvest 7, 2611 AX, Delft The Netherlands
Availability and Online Documentation: Free download with manual and supporting material at: http://public.deltares.nl/display/XBEACH/Home
Year first available: 2004
Hardware required: IBM compatible PC
Software required: MS Windows (tested on Windows XP)
Programming language: FORTRAN 99
Program size: 4.9 MB

1. Introduction

Historically coastal modelling software has developed out of different constraints from fluvial software, due to the necessity of representing different characteristics of hydraulic behaviour. Parameters like wind and tidal forces, which have high influence in the coastal environment (de Vriend, 1991), have minor effects in fluvial environments. Conversely, a longitudinal slope and varying initial water level, which are very important in river modelling, are not considered important in coastal modelling. However, the hydraulic calculations are similar, hence coastal software can be applied in fluvial areas. The application of a code outside its original domain needs to be verified and tested comprehensively before wider application is attempted.

XBeach is open source coastal software developed to model coastal flooding, sediment transport and morphological changes in two dimensions. The software contains a number of sub-routines which solve the non-stationary two dimensional shallow water equations that are able to calculate a fluvial flood wave. Open source codes provide payment-free software (usually under the GNU Public License – http://www.gnu.org/licenses/gpl.html) to users, which is a key advantage in developing countries (Bitzer, 2004; Lanzi, 2009). This approach allows the user to modify the code to meet their specific requirements (Henley and Kemp, 2008) and can lead to a significant development and improvement of the code, whilst affording flexibility.

This research tests the validity of applying this freely available software in a cross-over domain (fluvial environments), which opens up its use to a greater number of professionals, and also permits use in coastal/river transition zones such as estuarine areas. Due to the morphological tools available within the software, specialists would also have the possibility of accessing free 2D

* Corresponding author. Tel.: +31 15 2151895; fax: +31 15 3122921.
E-mail addresses: isnaeni@gmail.com (I.M. Hartanto), l.beevers@unesco-ihe.org (L. Beevers), i.popescu@unesco-ihe.org (I. Popescu), n.g.wright@leeds.ac.uk (N.G. Wright).

1364-8152/$ – see front matter
doi:10.1016/j.envsoft.2011.05.014

sediment transport capabilities. XBeach has generally been used as a stand-alone model for small scale coastal applications. It has many capabilities such as: depth-averaged shallow water equations including subcritical and supercritical flow, time-varying wave action balance, wave amplitude effect and the depth-averaged advection-diffusion equations (Roelvink et al., 2009). This paper focuses solely on the depth-averaged shallow water equations solver.

The main objective of the development of the XBeach was to provide modellers with a robust and flexible environment where the concepts of dune erosion, over washing and breaching can be tested (Roelvink et al., 2009). During the code development, the stability of the numerical method was considered as a top priority. Consequently, first order accuracy was accepted since the software concentrated on representing near shore and swash zone processes which have strong gradients in time and space (Roelvink et al., 2008). Such accuracy is the norm in river modelling software.

The objective of this paper is to test the applicability of this coastal software (XBeach) in the fluvial environment. This is completed through a number of tests which are designed to recreate particular hydraulic problems encountered in fluvial flooding scenarios. The tests include comparison to semi-analytical calculations, other modelling codes and laboratory experimental results. The aim is to demonstrate that an open source approach is also applicable in the fluvial environment.

2. Theoretical background

2.1. Numerical methods

The increased demand for improved safety against flooding, prompted the development of mathematical models which describe flow propagation in rivers. These mathematical models, in most cases, do not have an analytical solutions and are solved using numerical methods (Ferziger and Peric, 1999). Flow description in rivers, lakes and coasts are long waves, which can be described by means of the so-called Shallow Water Equations. These are a hyperbolic set of partial differential equations depending on the nature of the problem to be solved. These equations describe the mass conservation and momentum conservation.

Significant effort during the 1980's and 1990's was devoted to defining efficient and accurate numerical methods for hyperbolic systems. Mathematically the hyperbolic equations permit discontinuous solutions and their numerical integration should lead to the computation of such discontinuities sharply and without oscillations.

The differential form of the Shallow Water equations, in the reference framework of Fig. 1, are:

$$\frac{\partial u}{\partial t}+\frac{\partial f}{\partial x}+\frac{\partial g}{\partial y}=s,\ \text{or}\ \frac{\partial u}{\partial t}+\mathrm{B}\frac{\partial u}{\partial x}+\mathrm{C}\frac{\partial u}{\partial y}=s\quad\text{with B}=\frac{\partial f}{\partial u}\ \text{and C}=\frac{\partial g}{\partial u}\tag{1}$$

Where:

$\Omega\subseteq\mathbb{R}^2$ is the domain of computation; σ is any open subset of $\mathbb{R}^2$ with boundary Γ n is the outward unit normal.

The vectors included in the equation are:

$$\mathrm{u}=\left(h,q_x,q_y\right)^T$$
$$\mathrm{f}=\left(q_x,\frac{q_x}{h}+\frac{g}{2}h^2,\frac{q_xq_y}{h}\right)^T,\quad \mathrm{g}=\left(q_x,\frac{q_xq_y}{h}+\frac{q_y^2}{h}\frac{g}{2}h^2\right)^T\tag{2}$$
$$\mathrm{s}=\left(0,gh\frac{\partial h_o}{\partial x},gh\frac{\partial h_o}{\partial y}\right)$$

With q(x,t) -the unit-width discharge,

h_o(x, y)-the depth under the reference plane in Fig. 1,

ζ(x, y, t)-the elevation over the same reference plane,

h(x, y, t) = ho + ζ

g − the gravitational acceleration

s − the source term which accounts for the bottom slope

Γ is the boundary of σ.

B and C the Jacobian matrices of the fluxes f and g respectively.

Equations (2) are the conservative form of the Shallow Water equations (all the spatial derivatives of the unknowns are in the form of a divergence operator). In the case of a flat bottom ($h_o = 0$) the right-hand side of the equation is 0 and the equation is the strong conservation form of the Shallow Water equations.

The Shallow Water equations have an infinite hierarchy of conservative forms (Ambrosi, 1995) expressing the conservation of mass, energy, discharge rate, velocity, etc. Any two of these equations

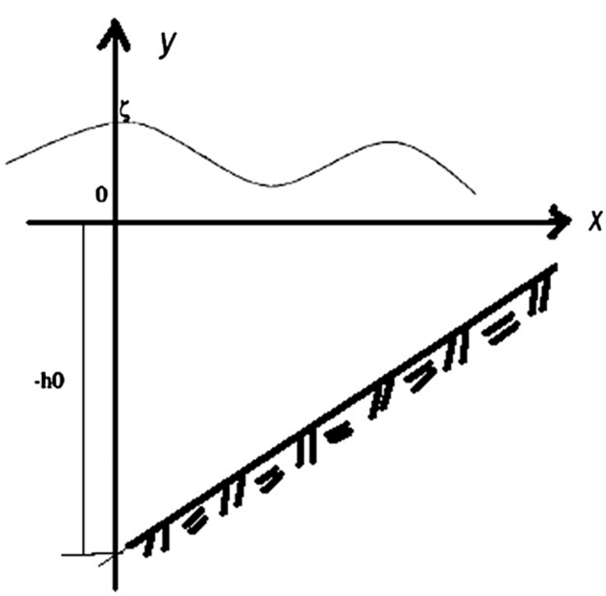

Fig. 1. Elevation and Depth for Shallow Water equations.

Table 1
Summary of tests completed.

Test no.	Name	Description	Figure no.
1a, 1b	Semi-analytical	Comparison of the model runs with semi-analytical solutions	Fig. 3
1c, 1d		M1, M2 curves (mild slope); S2, S3 curves (steep slope)	
2a	Idealised	Flow in a straight idealised channel	Fig. 4
2b		Flow in an embanked straight idealised channel	
2c		Flow in a meandering idealised channel	Fig. 5
3	EA case 1	Wetting and drying of a disconnected body	Fig. 6a & b
4	EA case 2	Low momentum flow	Fig. 7
5	EA case 3	Momentum conservation	Fig. 8
6	EA case 4	Flood propagation over a plain	Figs. 9 & 10
7	EA case 5	Dam break over a valley	Figs. 11 & 12
8a	EA case 6	IMPACT: Hydraulic jump and wake zone (laboratory scale)	Fig. 13
8b		IMPACT: Hydraulic jump and wake zone (realistic scale)	Fig. 14
9	Experimental	Dam break through an urban area	Fig. 15