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# Preface Special Issue "Advances in Numerical Modelling of Hydrodynamics"

Georges Kesserwani[1,*], Siegfried Müller[2], Daniel Caviedes-Voullième[1]

[1]*Pennine Water Group, Dept. of Civil and Structural Engineering, University of Sheffield, UK*
[2]*Institut fur Geometrie und Praktische Mathematik, RWTH Aachen, Templergraben 55, D52056, Aachen, Germany*

## 1. Introduction

Mathematical and numerical models that deal with hydrodynamics have transformed the way river engineering are practiced, and are possibly worth of a comprehensive review of developments in their own right (Knight 2013a, Knight 2013b, Duran and Marche 2014, Xing and Shu 2014, Stansby 2013). Developments in numerical methods and computing power continue to grow, to cite just a few (Caviedes-Voullième and Kesserwani 2015, Kesserwani et al. 2015, Sanders et al. 2010, Dawson et al. 2013, Cao et al. 2015, George 2011, Smith and Liang 2013, Lacasta et al. 2013, Zhou et al. 2013, Donat et al. 2014, Zanotti et al. 2015, Delis et al. 2011, Juez et al. 2014, Jian et al. 2015, Ran et al. 2015, Murillo and Garcia-Navarro 2010, Gerhard et al. 2015, Marsooli and Wu 2015, Swartenbroekx et al. 2013, Guan et al. 2014, Kim et al. 2014). This growth has opened-up opportunities to increase the accuracy, robustness and computational complexity of latest simulation models, and to address issues of practical relevance for modelling hydrodynamic processes. Particular examples include the treatment of the sink/source terms involved in the governing equations, parameter sensitivity analysis, the adoption of more sophisticated numerical schemes for real-scale simulations.

To exploit such opportunities, there is a growing necessity to promote interdisciplinary research across a wider range of experts from mathematics, engineering, physics and computer sciences to bridge gaps and to establish a common research perception, in order to tackle the research area in a more holistic way. This was the motivation of the *"Advances in Numerical Modelling of Hydrodynamics"* workshop held in Sheffield, UK, in March 2015. The workshop brought together 41 scientists and engineers from across different countries (France, Belgium, Switzerland, Italy, Spain, Portugal, Sweden, UK, Germany, Taiwan, USA, China, South Africa and Saudi Arabia) and career stages (from M. Sc. to professorial level). The contributions to this special issue were papers presented at the workshop, which were subject to peer-review by the workshop's scientific advisory board (details in Section 3). Selected papers, which were identified to offer *significant* scientific advance to modelling hydrodynamics, were extended and underwent a rigorous peer-review process. Acceptance into this Special Issue was based on comprehensive review reports, the authors addressing critical reviews, examination by the Guest editors and final decision by the Editor-in-Chief. This Special Issue is expected to benefit researchers and engineers addressing theoretical and applied aspects of Computational Hydraulics (see also Foreword).

## 2. Scope of the accepted papers

- Validity of advanced Riemann solvers for 1D river hydraulics: Approximate Riemann solvers are frequently used to solve problems in Computational Fluid Dynamics. Among these solvers, those build from the HLL (Harten et al. 1983) and (Roe 1981) approximations emerged very popular in the field of computational river hydraulics leading to many improved variants. In this issue, Franzini and Soares-Frazão compare the performance some latest versions of the HLL (Interalliée HLL and HLLS) and Roe (Augmented with energy balance) Riemann solvers, with a key focus

Corresponding authors. Tel.: +441142225746.
E-mail address: g.kesserwani@shef.ac.uk, mueller@igpm.rwth-aachen.de, Daniel.CaviedesVoullieme@b-tu.de

on solving 1D shallow flow with varying channel shapes and geometries. The paper diagnostically identifies the pros and cons of these emerging techniques, and discusses their implications for practical flow simulations.

- Coarse-mesh 2D flood model with subgrid-scale effects: Accurate and efficient integration of the geometrical details of urban area is an enduring challenge to 2D modelling of surface water flooding. Sub-grid models have been devised and applied to account for topographic variability that is too small to resolve with the computational mesh (Sanders et al. 2008). In this issue, Özgen et al. offer an extended formulation to the depth-averaged shallow water equations with anisotropic porosity to account for subgrid-scale effects while using coarse-grid simulations. Time-varying porosity terms are introduced as function of the water elevation in the cell and a cumulative distribution function of the unresolved bottom elevation to enable full inundation across a coarse cell. The applicability of the new equations is verified for various tests and compared with high-resolution reference simulations, with highlights on potential efficiency gain and on open-ended research challenges.
- Significance of the sediment diffusion term to hydro-morphodynamic modelling: Deterministic modelling of bedload transport in sedimentation engineering and computational river dynamics have rapidly emerged in recent years (Marsooli and Wu 2015, Kesserwani et al. 2014). In this issue, Bohorquez and Ancey examine the importance of sediment diffusion associated with advection in bed load transport. The concept of sediment transport is revisited by further intertwining with probabilistic theory to identify the role played by particle diffusion in bed load transport. Based on the shallow water equations coupled with Exner equation, numerical simulations are performed to reproduce channel degradation and antidune development in gravel bed streams over steep slopes. Validations with respect to flume experiments is performed to illustrate the improvement associated with the inclusion of the diffusion term.
- Physical and numerical modelling of Hele-Shaw flow: Shallow water flows through thin geometries are often associated with Hele-Shaw flow (Boyko et al. 2015). For such flows, the advective (inertial) forces are small compared with viscous forces, and the boundary conditions are defined by pressures and surface tensions. In this issue, Kalogirou et al. explore analytically, numerically and experimentally the damped motion of driven water waves in a Hele-Shaw tank. The equations governing the hydrodynamics of the problem are derived from a variational principle for shallow water, but with further inclusion of surface tension effects, linear momentum damping and incoming volume flux through the boundary at which waves are generated. The discontinuous Galerkin method is applied to solve the model equations. Numerical results are validated against exact linear wave solutions and laboratory experiments of artificially driven waves in the Hele-Shaw tank.
- Time step enlargement of an explicit finite volume shallow water model: Explicit numerical methods, although dictate small time steps due to a Courant–Friedrich–Lewy (CFL) stability condition < 1, remain undoubtedly one of the most popular approaches in solving for unsteady shallow water flows (Morales-Hernández et al. 2013). In this issue, Morales-Hernandez et al. extend their approach for relaxing the CFL condition to > 1 to enable larger time steps in solving the inviscid shallow water equations on unstructured triangular meshes. This paper especially focuses on the handling of information transfer facing the unstructuredness of the meshes. The proposed approach is compared against conventional first- and second-order explicit schemes to demonstrate its potential impacts on accuracy and efficiency.
- Modelling air-entrainment in shallow water flow: In some situations, such as an impact jet or a jump formation, air-entrainment into shallow water flow can cause two layer water/air with complex turbulent mixing (Lubin et al. 2006, Chanson et al. 2006). Physical and numerical modelling of these processes is challenging and demanding due to: the presence of the macroscopic interface, multiple parameterization setting and, bubbles formation, interaction and transport throughout the free-surface. In this issue, Lopes et al. examine numerically and experimentally the aspects of a 3D circular plunging jet of water entering a pool. An explicit term is introduced to detect bubble formation and air-entrainment at the free-surface. The capacities of a Volume-of-Fluid based model to detect the free-surface and predict the velocities inside the

water phase is studied, as well as mesh dependency issues. The results obtained are further compared and discussed with similar cases in the literature.

- Comparative study of topography integration techniques in 3rd-order Discontinuous Galerkin models: Real-world shallow water flows occur over uneven topographies. Topography discretisation techniques are unavoidable for the design of shallow water numerical models (Murillo and Garcia-Navarro 2010, Kesserwani 2013). Several techniques have been proposed, which are commonly constructed based on the assumption of motionless steady state. However, their ability to handle moving-water steady state over discontinuous terrain shapes is still questioned. In this issue, Caleffi et al. unravel the capability of five different numerical approaches for discretisation of free-surface over bottom steps. A systematic and diagnostic 1D analysis is presented crossing aspects of accuracy-order, conservation properties, continuous vs. discontinuous terrain shapes, steady and unsteady flows.
- Theoretical and sensitivity analysis of the divergence discretisation of bed slope source term: The divergence formulation of the bed slope source term (Valiani and Begnudelli 2006) within the numerical solution of the shallow water equations has emerged as physically-based technique to easily, efficiently and accurately integrate the discretisation of the topography in a wide range of numerical models and on different mesh structures (Kim et al. 2014, Hou et al. 2013). In this issue, Bruwier et al. present a theoretical analysis of the divergence bed slope formulation going beyond the classical assumption of locally-constant free-surface elevation and considering the influence on energy balance. The analysis is performed for the case of a single topographic step and is then tested numerically. A calibration parameter is introduced and tested to further improve the use of the divergence formulation on the basis to minimize the energy variation.

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