

Springer Water

Philippe Gourbesville
Guy Caignaert *Editors*

Advances in Hydroinformatics

Models for Complex and Global Water
Issues—Practices and Expectations

 Springer

Springer Water

Series Editor

Andrey Kostianoy, Russian Academy of Sciences, P. P. Shirshov Institute of Oceanology, Moscow, Russia

Editorial Board

Angela Carpenter, School of Earth & Environment, University of Leeds, Leeds, West Yorkshire, UK

Tamim Younos, Green Water-Infrastructure Academy, Blacksburg, VA, USA

Andrea Scozzari, Area della ricerca CNR di Pisa, CNR Institute of Geosciences and Earth Resources, Pisa, Italy

Stefano Vignudelli, CNR - Istituto di Biofisica, Pisa, Italy

Alexei Kouraev, LEGOS, Université de Toulouse, TOULOUSE CEDEX 9, France

The book series Springer Water comprises a broad portfolio of multi- and interdisciplinary scientific books, aiming at researchers, students, and everyone interested in water-related science. The series includes peer-reviewed monographs, edited volumes, textbooks, and conference proceedings. Its volumes combine all kinds of water-related research areas, such as: the movement, distribution and quality of fresh-water; water resources; the quality and pollution of water and its influence on health; the water industry including drinking water, wastewater, and desalination services and technologies; water history; as well as water management and the governmental, political, developmental, and ethical aspects of water.

Philippe Gourbesville · Guy Caignaert
Editors

Advances in Hydroinformatics

Models for Complex and Global Water
Issues—Practices and Expectations

 Springer

Editors

Philippe Gourbesville
Polytech Lab
Université Côte d'Azur
Sophia Antipolis, France

China Institute of Water Resources
and Hydropower Research
Beijing, China

Guy Caignaert
Ecole Nationale des Arts et Métiers
Hydrotechnique Society of France
Paris, France

ISSN 2364-6934

Springer Water

ISBN 978-981-19-1599-4

<https://doi.org/10.1007/978-981-19-1600-7>

ISSN 2364-8198 (electronic)

ISBN 978-981-19-1600-7 (eBook)

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2022

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd. The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

With the current digital environment in modern societies and its development, hydroinformatics defined as management of information related to the water sector using ICT tools is becoming over the last decade a broader domain of engineering technology and sciences. Modelling and simulation are historically the points of departure for hydroinformatics and are one of the most important parts of it. Neither the SimHydro cycle of international conferences since 2010 nor the present book has the purpose or ambition to cover thematically the whole extent of the subjects. The main purpose is to concentrate on a limited number of specific areas and subjects that are not usually considered as such during most global international conferences or publications.

Modelling in fluid mechanics, hydraulics and hydrology, whether using digital tools or scale models, has reached sufficient maturity to be in daily use by engineers for analysis, for design and for communication. Increasingly, complex cases can be handled thanks to ever-more sophisticated tools and increasingly abundant computing power and data resources. The emerging environment populated with new generation of sensors, using cloud computing resources, producing big data, is challenging the current practices of modelling and requests innovation in methodology and concepts for a real integration into the decision-making processes that are more and more requested for crisis management. The computing resources allow today to enter the real-time application and open the door to decision support systems that could be mobilized at different stages including during major water related crisis. At the same time, the request to integrate vulnerability and resilience dimension in the various engineering approaches is becoming more and more frequent, especially for environments directly exposed to major natural hazards like floods and inundations.

With respect to these issues, however, a number of questions still remain open and concentrate development efforts: coupling of models, data acquisition and management, uncertainties (both epistemic and random) of results supplied by models, use of 3D CFD models for complex phenomena and for large-scale problems, added value of AI processes combined to deterministic approaches, etc. All these points are continuously explored and investigated by researchers, scientists and engineers. Like in all scientific domains, most recent and advanced developments must be discussed and

shared regularly in a growing community that has to face every day more challenging and complex situations. Despite the difficult situation related to the COVID crisis and the related constraints, the SimHydro 2021 conference, following the five previous editions, has contributed to this objective by providing a platform for exchanges and discussion for the different actors in the water domain through an innovative hybrid mode combining on-site and online attendance. The exercise was challenging for participants and organizers who had to invent a new way to present, to share and to exchange through various protocols. If the pandemic situation has popularized the use of video conferencing platforms and developed the requested skills to ensure an efficient online presentation, the on-site participants have all underlined the interests of the synergy during the coffee and the lunch breaks, especially under the sunshine of the French riviera.

SimHydro is a permanent cycle of conferences held every 2 years, hosted by Polytech Nice Sophia and organized by the Société Hydrotechnique de France (SHF) and its partners. It aims, as the subject, at recent advances in modelling and hydroinformatics and at the participation and exchanges at European scale (it is open to all other researchers and participants, but the purpose is to maintain a specific platform for the region that was a birthplace of both domains).

The latest SimHydro conference was held in Sophia Antipolis, France, from 16 to 18 of June 2021. The conference was jointly organized by the Société Hydrotechnique de France (SHF), the Association Française de Mécanique (AFM), Université Côte d'Azur/Polytech Nice Sophia and with the support of the International Association for Hydro-Environment Engineering and Research (IAHR), the Environmental & Water Resources Institute (EWRI) of the American Society of Civil Engineers (ASCE) and the Canadian Society for Civil Engineering (CSCE). Several sponsors also supported the conference: CNR, IRSN, EDF, DHI France and SETEC-HYDRATEC. The conference attracted 220 delegates from 38 countries who participated in 30 sessions where 124 papers were presented. The programme was organized around fourteen main themes:

1. Hydro-environmental issues and extreme situations
2. Uncertainties and data assimilation
3. AI solutions for water
4. Intensive computing for hydraulic simulations
5. Extreme in hydraulics: how to deal with?
6. Decision support system and models: concepts, design, challenges, implementation and operation
7. Real-time management and models
8. Hydraulic structures and networks: real-time operation
9. Scale models in hydraulics and their place and complementary in simulation concepts
10. Modelling methods and tools for floods management
11. 3D multi-phase flows (experiments and modelling)

12. Hydraulic machinery
13. Diphasic flows and cavitation
14. Modelling in ecohydraulics and morphology.

The general theme of the conference was focused on “Models for complex and global water issues—Practices and expectations”. The water field is continuously mobilizing models for addressing complex issues and new challenges. Within the context of the climate change, the water issues are exacerbated with the competition among uses. The limited water resources request from the modern societies to review some of the historical paradigms traditionally used and to promote new approaches for a sustainable management. The combined complexity and vulnerability of large urban environments request a deep understanding of water uses and environmental synergy. At the same time, water-related natural hazards are contentiously straightening modern societies that have to adapt and implement a more resilient environment. In parallel, in the industrial sector, the search for a high level of efficiency for hydraulic machinery requests to simulate complex processes. Under all these situations, the models currently used represent only partly the physical phenomena involved, the scale of the processes, the hypothesis included within the different numerical tools, etc. The design and the operation of relevant models represent a challenging task for the modeller who is responsible of the knowledge part of a global system that is dedicated to support the decision-makers.

Within general themes of the conference, topics like coupling of models, data assimilation and uncertainties, urban flooding, data and uncertainties in hydraulic modelling, model efficiency and real situations, new methods for numerical models, hydraulic machinery, 3D flows in the near field of structure, models for complex phenomena have been covered. The conference, by attracting researchers, engineers and decision-makers, has promoted and facilitated the dialogue between various communities, especially with several special sessions frequently linked to ongoing European Research projects and to the catastrophic ALEX storm event affecting the French and Italian catchments in October 2020.

The ALEX storm was targeting several upstream sectors in mountainous catchments on the French Riviera and in Italy on the 2 of October 2020. The recorded extreme rainfall volumes—among the ten most intense events never recorded in France—have generated massive runoff associated with sediment transport. The magnitude of the processes has produced major morphological changes and induced the destruction of many communication infrastructures and buildings. The recovery phase was complex with key questions on how to rebuild and, more widely, on the uses to promote in the mountainous upstream part of the catchments. The session was gathering feedback from local population, victims, first responders, meteorologists, insurance representatives and decision-makers. The session was organized in order to maximize the return of experience for the modeller’s community.

Exchanges with participants have been very fruitful on crucial questions related to the crisis management during extreme flood events, the needs for operational forecasting systems, the state of the art in research and development in the domain of numerical fluid mechanics, the stakeholder’s capacity to understand results, the

means for dialogue directly or indirectly between the stakeholders and the model developers, the information's exchange between stakeholders and developers.

In order to contribute to this dialogue and to provide useful references, following the successful previous experiences of 2012, 2014, 2017 and 2019, the organizers of SimHydro 2021 have decided to elaborate this book. This volume gathers a selection of the most significant contributions received and presented during the conference. The objective is to provide the reader with an overview of the ongoing developments and the state of the art taking place in three major sections that are:

- numerical methods and uncertainties;
- flood modelling and mitigation actions;
- advanced modelling solutions.

Obviously, all dimensions of these themes cannot be covered in a single book. However, the editors are convinced that the contents may contribute to provide to the reader essential references for understanding the actual challenges and developments in these areas of the hydroinformatics field.

This volume represents the sum of the efforts invested by the authors, members of the scientific committee and members of the organizing committee. The editors are also grateful for the dedicated assistance of the reviewers who worked tirelessly behind the scene to ensure the quality of the papers. We hope this book will serve as a reference source on hydroinformatics for researchers, scientists, engineers and managers alike.

Sophia Antipolis, France
August 2021

Philippe Gourbesville
Guy Caignaert

Contents

Part I Numerical Methods and Uncertainties

1	Local Downscaling of Shallow Water Simulations	3
	Pascal Finaud-Guyot and Vincent Guinot	
2	SW2D-Lemon: A New Software for Upscaled Shallow Water Modeling	23
	Joao Guilherme Caldas Steinstraesser, Carole Delenne, Pascal Finaud-Guyot, Vincent Guinot, Joseph Luis Kahn Casapia, and Antoine Rousseau	
3	A 1D Numerical Tool for Real Time Modelling of a Complex River Network	41
	Benoît Camenen, Jean-Baptiste Faure, Stéphanie Décanis, and Laurent Dieval	
4	Rapid Simulations of Large Scale Flood Inundations Using Porosity Functions	53
	Vita Ayoub, Carole Delenne, Pascal Finaud-Guyot, David Mason, Marco Chini, Patrick Matgen, Ramona-Maria Pelich, and Renaud Hostache	
5	New Developments in a 1D+ ISM Model for Operational Purposes	61
	Yassine Kaddi, François-Xavier Cierco, Jean-Baptiste Faure, and Sébastien Proust	
6	Application of a Modified Parareal Method for Speeding Up the Numerical Resolution of the 2D Shallow Water Equations	85
	Joao Guilherme Caldas Steinstraesser, Vincent Guinot, and Antoine Rousseau	

7	Validation of a General-Purpose Erosion-Sedimentation Model on a Laboratory Experiment	109
	Noémie Gaveau, Carine Lucas, and Frédéric Darboux	
8	Modelling Culverts in Basilisk	121
	Zied Amama, Nicolas Branco, Cheikh Mangara, Kevis Mbonyinshuti, Qiyu Yu, Thibaut Cottancin, Sarah Vigoureux, Pierre Brigode, Olivier Delestre, and Pierre-Yves Lagrée	
9	Uncertainty Quantification in Hydrodynamic Modeling Using the Example of a 2D Large-Scale Model of the River Elbe	139
	Rebekka Kopmann, Sebastian Hudjetz, and Andreas Schmidt	
10	Quantification of Historical Skew Surges: Challenges and Methods	159
	Emmanuelle Athimon, Nathalie Giloy, Thierry Sauzeau, Marc Andreevsky, and Roberto Frau	
11	Sensitivity Analysis of the Digital Twin of the Canal of Calais to the Outlet Gate Modelling	175
	Roza Ranjbar, Lucien Etienne, Eric Duviella, and Jose Maria Maestre	
12	Integrated Hydraulic-Hydrological Assimilation Chain: Towards Multisource Data Fusion from River Network to Headwaters	195
	L. Pujol, P.-A. Garambois, J. Monnier, P. Finaud-Guyot, K. Larnier, and R. Mosé	
13	Meandering of the Venoge River at Bois-de-Vaux: In Situ Measurements Versus 2D Numerical Predictions	213
	Charlotte Dreger, Erik Bollaert, and Oliver Stauffer	
14	How to Optimally Represent Riverbed Geometry with a Simplified Cross-Section Shape in Shallow Water Models	225
	Violeta A. Montoya-Coronado, Carole Delenne, Pascal Finaud-Guyot, and Renaud Hostache	
15	Evaluate the Influence of Groynes System on the Hydraulic Regime in the Ha Thanh River, Binh Dinh Province, Vietnam	241
	Thanh-Nhan-Duc Tran, Quang Binh Nguyen, Dinh Tam Luc Le, Tien Dung Nguyen, Ngoc Duong Vo, and Philippe Gourbesville	

16 Comparison of Streamflow Estimated by Image Analysis (LSPIV) and by Hydrologic and Hydraulic Modelling on the French Riviera During November 2019 Flood 255
Sarah Vigoureux, Léa-Linh Liebard, Aubin Chonoski, Etienne Robert, Louis Torchet, Valentin Poveda, Frédérique Leclerc, Jérémy Billant, Rémi Dumasdelage, Gauthier Rousseau, Olivier Delestre, and Pierre Brigode

17 Analysis of Triple Rectangular Plates Configurations Impacts on Local Scour Around Cylindrical Single Bridge Pier 275
Alireza Pourzaker Arabani and Hooman Hajikandi

Part II Flood Modelling and Mitigation Actions

18 2-D Simulation of Flow Entering a Building 291
André Paquier, Cheikh Mangara, Emmanuel Mignot, Xuefang Li, and Benjamin Dewals

19 Investigation of the Hydraulics in Flooded Housing Estate 303
Augustin Doumic, Frédérique Larrarte, Rajae Rtimi, and Nicole Goutal

20 Benefit of Coupling 1D-2D Model Over an Urban Area to Assess Runoff During a Storm Event 315
Nathalie Bertrand, Morgan Abily, Malo Lambert, and Olivier Delestre

21 Stream Rehabilitation Design in a Potentially Protected Forest Catchment in Singapore 329
Jiandong Liu, Dong Eon Kim, Canh Tien Trinh Nguyen, Yixiong Cai, and Shie-Yui Liong

22 Applications of a Physics Based Distributed Integrated Hydrological Model in Flood Risk Management 349
Erwan Allard and Jean-Paul Ducatez

23 Determination and Application of Dynamic Rainfall Threshold for Flash Flood Warning 361
Xiaoyan Zhai, Changjun Liu, Qiang Ma, Ronghua Liu, Xiaolei Zhang, and Qi Liu

24 Optimized Reservoir Prior Release Operation for Flood Control Considering Operational Weekly Ensemble Hydrological Forecast 369
Daisuke Nohara

25	Geographical Cluster of Flash Flood Hazards in Jiangxi, China: A Spatial Analysis Perspective	383
	Xiaoxiang Zhang, Yuehong Chen, Xiuqin Fang, Liliang Ren, and Qiang Ma	
26	Analysis of Extreme Precipitation During the Mediterranean Event Associated with the Alex Storm in The Alpes-Maritimes: Atmospheric Mechanisms and Resulting Rainfall	397
	Raphaël Chochon, Nicolas Martin, Thomas Lebourg, and Maurin Vidal	
27	Are Hydrologic-Hydraulic Coupling Approaches Able to Reproduce Alex Flash-Flood Dynamics and Impacts on Southeastern French Headwaters?	419
	Pierre Brigode, François Bourgin, Rabab Yassine, Olivier Delestre, and Pierre-Yves Lagrée	
28	Improving the Efficiency of Flash Flood Forecasting and Warning System in Thailand	437
	Apimook Mooktaree, Piyamarn Sisomphon, Sathit Chantip, and Ticha Lolupiman	
29	Study on Forecasting and Alarming Model of Flash Flood Based on Machine Learning	455
	Wen-Chuan Wang, Yan-Wei Zhao, Chang-Jun Liu, Qiang Ma, and Dong-Mei Xu	
30	Numerical Assessment of Sediment Supply Impacting Flash Flood Propagation in Mountainous Confluences	471
	Xu-Feng Yan, Chang-Jun Liu, Dong-Ya Sun, Qiang Ma, and Xie-Kang Wang	
31	Large Wood Transport-Related Flood Risks Analysis of Lourdes City Using Iber-Wood Model	481
	Margaux Quiniou, Guillaume Piton, Virginia Ruiz Villanueva, Cédric Perrin, Jeremy Savatier, and Ernest Bladé	
32	A Study on Flood Inundation Mapping of Surma River Floodplain Under Extreme Flood Scenario	499
	Purnima Das, Fahim Ahmad, Afeefa Rahman, and Md. Sabbir Mostafa Khan	
33	A Framework for Evaluating Performance of Large-Scale Nature-Based Solutions to Reduce Hydro-Meteorological Risks and Enhance Co-benefits	515
	Laddaporn Ruangpan and Zoran Vojinovic	

34 Managing Droughts in Northern Germany—The Reconnect NBS Approach and Water Resources Model for Vier- Und Marschlande Area, Hamburg, Germany 529
 Peter Fröhle, Natasa Manojlovic, Yohannis Tadesse, Angelika Gruhn, Hartmut Dittrich, and Christian Ebel

35 Opportunities and Challenges of Natural-Based Solutions in Urban Areas—French Case Studies 551
 Jelena Batica and Philippe Gourbesville

36 The 1915 Mud-Debris Flow at San Fruttuoso Di Camogli: Modeling the Collapse Effects in the Portofino Pilot Area of the H2020 Reconnect Project 573
 Guido Paliaga, Steven N. Ward, Fabio Luino, Laura Turconi, and Francesco Faccini

37 Benefits of Green Infrastructure for Flood Mitigation in Small Rural Watersheds—Case Study of the Tamnava River in Serbia 591
 Ranko S. Pudar and Jasna Plavšić

38 Modelling Nature-Based Solutions with Quasi-2D Model 605
 Leng-Hsuan Tseng, Zoran Vojinovic, Meng-Hsuan Wu, Dong-Jiing Doong, and WeiCheng Lo

39 Bregana River Basin: Hydrodynamic Modeling and Analysis of NBS Suitability Within the Reconnect Project 615
 Draženka Kvesić, Ratko Ramušćak, and Božidar Deduš

Part III Advanced Modelling Solutions

40 Numerical Simulation of the Interaction Between the Jet and a Pelton Runner Under Low Head 637
 Jean Decaix, Anthony Gaspoz, Steve Crettenand, and Cécile Münch-Alligné

41 Discretization Uncertainties of Flow and Fatigue Damage Simulations of a Reversible Francis Pump-Turbine at Off-Design Operation in Turbine Mode 649
 Daniel Biner, Philippe Bontemps, Drazen Dujic, and Cécile Münch-Alligné

42 Hybrid Modeling of the Massongex-Bex-Rhône Hydropower Plant on the Rhone River in Switzerland 671
 Pedram Sahraei, Samuel L. Vorlet, and Giovanni De Cesare

43 Effect of the Variable Speed on the Hydraulic Behavior of the Caniçada Francis Turbine 685
 Olivier Pacot, Thomas de Colombel, Claire Segoufin, Joachim Delannoy, Sebastian Leguizamon, João Delgado, Miguel Roque, and Cécile Münch-Alligné

44 Shape Optimization of Spillways Design Using a Gradient Based Algorithm 705
 Fatna Oukaili, Yvan Bercovitz, Cédric Goeuru, Fabrice Zaoui, Thomas Fonty, and François Jouve

45 Challenges for Realtime DSS: Experience from Aquavar System 719
 Philippe Gourbesville, Hezouwé Amaou Tallé, Masoud Ghulami, Ludovic Andres, and Marc Gaetano

46 Extraction of Filters Applicable to Flood Forecasting Model and Performance Evaluation by Information Criterion 737
 Masayuki Sugiura and Kohji Tanaka

47 Three-Dimensional Sediment Transport Modeling of the Gironde Estuary 753
 Nicolas Huybrechts, Pablo Tassi, and Fabrice Klein

48 Calibration of 1D and 2D Fluvial Models with a Metamodel Based Optimization 773
 Guillaume Benefice, Luc Duron, Amaya Villanueva, and Rui Yang

49 Coupling Surface Grain-Size and Friction for Realistic 2D Modelling of Channel Dynamics on Massive Bedload Deposition 795
 Matthieu Gonzales de Linares, Florian Ronzani, Alain Recking, Vincent Mano, and Guillaume Piton

50 Hydraulic Modelling Studies for the Rehabilitation of Waterways on the Congo River 809
 Olivier Bertrand, Jean-Noël Arnaud, Thibault Oudart, Luc Bazerque, and Gabriel Mokango

51 Study of Coastline Dynamics and Impact of a Hydraulic Structure in Menton, France 825
 Pagedame I. Game, Philippe Audra, and Philippe Gourbesville

52	Simulation of the Alex Storm Flash-Flood in the Vésubie Catchment (South Eastern France) Using Telemac-2D Hydraulic Code	847
	Rabab Yassine, Mickaël Lastes, Aymeric Argence, Alan Gandouin, Clément Imperatrice, Pierre Michel, Ruida Zhang, Pierre Brigode, Olivier Delestre, and Florent Taccone	
53	Modelling Cyclonic Events in the Pacific	865
	Olivier Bertrand, Anne Levasseur, Thibault Oudart, and Mehdi-Pierre Daou	
54	Merenptah: High Tide Level Forecasting Tool with Application to the Gironde Estuary	875
	Nicolas Chini, Cécile Calas, Adelaïde Martin-Herrou, Hélène Habarou, Christian Raffourt, and Philippe Bardey	
55	Operational Methodology for the Assessment of Typhoon Waves Characteristics. Application to Ninh Thuan Province, Vietnam	887
	Thanh-Nhan-Duc Tran, Quang Binh Nguyen, Trung Tri Nguyen, Ngoc Duong Vo, Cong Phong Nguyen, and Philippe Gourbesville	
56	Improving Water Levels Forecast in the Gironde Estuary Using Telemac2D and Data Assimilation by Inferring Time-Dependent Boundary Conditions	903
	Vanessya Laborie, Nicole Goutal, and Sophie Ricci	
57	Implementation of a Hydrologic Model as an Element of the Litter-TEP Service—Marine Litter Tracking and Stranding Forecast—Or for the Understanding of the Coastal Patterns Change	921
	Anne Vallette, Quentin Gunti, Fatimatou Coulibaly, and Anne-Laure Beck	
58	How Strong Are Our Levees? Hydraulic Analysis Based on Polder2C's Project in Situ Testing	937
	Stephanus J. H. Rikkert, Cédrine Alleon, Ichrak Khaldi, Salah Shaiek, Kristof Verelst, Masoumeh Ebrahimi, Sandra Soares-Frazão, Sami Kaidi, Hassan Smaoui, and Philippe Sergent	
59	Further Enhancement of Satellite DEM Resolution and Accuracy Using Machine Learning and Remote Sensing Data	955
	Dong Eon Kim, Jiandong Liu, Ludovic Andres, Philippe Gourbesville, and Shie-Yui Liong	

60 Investigating the Behaviour of Leaky Barriers with Flume Experiments and 3D Modelling 965
 Shannon Leakey, Caspar J. M. Hewett, Vassilis Glenis, and Paul F. Quinn

61 Underground Flow Section Modification Below the New M3 Flon Metro Station in Lausanne 979
 Leona Repnik, Samuel Vorlet, Mona Seyfeddine, Azin Amini, Romain Dubuis, Giovanni De Cesare, Pierre Bourqui, and Pierre-Adil Abdelmoula

62 Numerical Simulation of the Hydraulic Behavior of Stepped Stairs in a Metro Station 1001
 Jackson Tellez-Alvarez, Manuel Gomez, and Beniamino Russo

63 Computational Fluid Dynamic Wave Modelling: Sensitivity Analysis of the Loading on Offshore Structures 1011
 Thibault Oudart, Sylvain Perrin, Olivier Bertrand, Bruno Chaffraix, and Delphine Le-Bris

64 Assessment of Smart Heating and Cooling System Based on Thermal Use of Shallow Aquifer 1023
 Philippe Gourbesville and Masoud Ghulami

65 Numerical Simulations for Multipurpose Reservoirs for Alpine Irrigation 1035
 Théo Gonin, Jean Decaix, Jérémy Schmid, Alexandre Gillioz, Damien Pettinaroli, and Cécile Münch-Alligné

66 Optimal Operation of Parallel Reservoirs System with Limited Storage Capacity for Flood Mitigation 1051
 Thanh Hao Nguyen and Philippe Gourbesville

67 Sizing Flood Control Storage of Reservoirs System in the Vu Gia Thu Bon Catchment 1065
 Thanh Hao Nguyen and Philippe Gourbesville

68 Integrating Epanet and FIWARE for Development of Water Distribution System Digital Twins 1081
 Chris Sweetapple, Elad Salomons, Franck Le Gall, Ahmed Abid, Lydia Vamvakeridou-Lyroudia, Albert S. Chen, and Joep van den Broeke

69 Assessment of Spanish Rivers Current and Future Ecological Status Using Urban Wastewater Dilution Factor 1087
 Morgan Abily, Vicenç Acuña, Wolfgang Gernjak, Ignasi Rodriguez-Roda, Manel Poch-Espallargas, and Lluís Corominas

70	Changes of River Discharge and Temperature by Using Distributed Runoff Model with the Global Warming Experiments, Frequency Analysis of Drought and Flood	1103
	Akira Kurihara, Daiki Omori, Kohji Tanaka, and Yutaka Oyagi	
71	Dracar: An Estuarine Transfer Function to Predict Dissolved Pollutant Fluxes to the Sea. Application for Radionuclides	1115
	Adrien Delaval, Céline Duffa, Ivane Pairaud, and Olivier Radakovitch	
72	Three-Dimensional Simulation of Bacterial Pollution in Nice Bay for Operational Application	1131
	Julien Larraun, Rémi Dumasdelaage, and Olivier Delestre	
73	Flood Analysis and Simulation Attempts of the Newly Proposed Capital City of Indonesia	1145
	Mingyan Wang, Philippe Gourbesville, Shie-Yui Liong, Dongeon Kim, and Jiandong Liu	
74	Impacts of Climate Change on Water Availability for the Vésudie Catchment, France	1165
	Masoud Ghulami, Philippe Gourbesville, and Philippe Audra	
75	A Spatiotemporally-Mixed-Runoff-Model-Based Artificial Intelligence Parameter Regionalization Application in Henan Province of China	1173
	Qiang Ma, Suqi Fan, Changjun Liu, Liang Guo, Liuqian Ding, and Dongya Sun	
76	Prediction of Index Rainfall Using a Cubist Model: A Case Study of Cheliff Watershed (Algeria)	1193
	Chafai Tarfaya and Larbi Houichi	
77	Assessment of Terrain Scenario Impacts on Hydrological Simulation with SWAT Model. Application to Lai Giang Catchment, Vietnam	1205
	Thanh-Nhan-Duc Tran, Quang Binh Nguyen, Ngoc Duong Vo, Rushawn Marshall, and Philippe Gourbesville	
78	Influence of Topography Resolution and Quality on Modeling Hydrological Processes in Pailon River Basin in the South of France	1223
	Paguedame I. Game, Philippe Audra, and Philippe Gourbesville	

79 Water Europe: Hydroinformatics for Water Resources and Water Related Hazards Management in Europe 1241
Philippe Gourbesville, Manuel Gomez Valentin,
Frank Molquentin, Caspar Hewett, Grzegorz Sinicyn,
and Ann van Griensven

80 HydroEurope—WaterEurope: 20 years of Practice in Collaborative Engineering for Hydroinformatics 1255
Philippe Gourbesville, Manuel Gomez Valentin,
Frank Molquentin, Caspar Hewett, Grzegorz Sinicyn,
and Ann van Griensven

Part I

Numerical Methods and Uncertainties

Numerical methods are a fundamental component of hydroinformatics solutions. The recent developments within the theoretical aspects associated to the availability of massive computing resources have open the door to new developments that are highly promising for the modellers involved within the water sector. This part gathers papers that are exploring new numerical approaches and analysing their added values. At the same time, several papers are questioning how good are the produced models i.e. how certain is the quality of solution of the original equations given the algorithm and software applied. Problems of methods for a number of years have been rather occulted by engineering community because of the everyday use of commercial software and an unfortunate idea that entered the minds of many, namely that now everything can be modelled and that modelling solves all problems. New methods and algorithms were developed and known mainly by research community and were not massively employed because of commercial software easy to obtain and offering user-friendly interfaces. The situation evolved over the last decade and, precisely, SimHydro conferences allow each time the projection of new methods towards engineering community through a number of specific papers like those found in this part.

Regarding the uncertainty problems, several papers of this part enter conceptual levels that change the category of traditional approach. In engineering project and practice, when modelling is concerned, next to everything is uncertain:

- *First*: do you need a model? A model of what? Do you know the phenomena you wish to model? Hopefully you do not expect that you will discover physical phenomena using models that are solutions of equations that describe these phenomena, what means that the latter are already known!

- *Then*: since known equations describe the physical laws that govern problems of your interest, what is the certainty of their numerical solutions provided by given algorithm?

- *Then*: are the data such as topography and similar sufficiently well-known and introduced in the model to be at the level of required certainty of the results of the latter?

- *Then*: suppose you are interested in flooding issues, and you use some industrial simulation software, are you sure that if through some tuning of resistance coefficients you could reproduce past observed flood then the results for exceptional catastrophic ungauged flood will be as good? And if not, how good?

- *Other level of uncertainty*: how certain are information concerning possibility of catastrophic dyke breaking along the river as compared to uncertainty of results obtained from possibly best modelling of open channel flow system? What is uncertainty of the conclusion of studies face to the question of a decision-making manager: “when, at which discharge observed upstream, should I evacuate cities and industries situated in lateral valley protected by dykes that can break?”. Here we are not any longer at the level of uncertainty of the results of modelling but at the level of uncertainty of consequences of decisions that, nevertheless, are based or conditioned by the results of the models. In other terms uncertainty in water resources management and engineering becomes the subject of overall approach and traditional sensitivity studies (Monte Carlo and similar) of the given model results are standard peripheral activity. Over the SimHydro editions, this general approach has gained interest and mobilized numerous teams in various contexts.

Numerical methods and uncertainties remain core components of SimHydro conferences and are now entering the real-time application dimension. Obviously, the topic will be enriched with new developments and applications in the coming years.

Philippe Gourbesville
Guy Caignaert
Sophia Antipolis, France
August 2021

Chapter 1

Local Downscaling of Shallow Water Simulations



Pascal Finaud-Guyot and Vincent Guinot

Abstract We present a method for the downscaling of low-resolution flow simulations in urban areas. The purpose is to reconstruct some flow variables over fine grids (cell size 1 m or less) from upscaled flow simulations over very coarse grids (cell size 10–50 m). The flow variables under consideration are the water depth and the norm of the unit discharge. These are two widely accepted indicators in flood hazard assessment. The method is assessed in the framework of perfect upscaling, whereby the coarse grid flow variables are exact averages of the fine grid simulation results. A simple reconstruction approach is used: the flow variables are transformed using a power law. The transform of the flow variable over a given cell in the high-resolution grid is computed as a linear combination of the transforms of the flow variables over the coarse resolution grid. The degrees of freedom in the method are the power of the transform, the number of coarse grid cells (called the neighborhood size) and the linear combination coefficients. The method is fitted by minimizing the RMSE between the exact (known) high resolution solution and the reconstructed one. The results show that (i) reconstructing the water depth is easier than reconstructing the unit discharge, (ii) flows involving shocks yield larger reconstruction errors than those involving rarefaction waves, (iii) the method is better when trained for a specific wave propagation direction.

Keywords Urban floods · Hazard mapping · High resolution reconstruction · Perfect upscaling

P. Finaud-Guyot · V. Guinot (✉)
Univ Montpellier, HSM, CNRS, Montpellier, IRD, Inria, France
e-mail: vincent.guinot@umontpellier.fr

P. Finaud-Guyot
e-mail: pascal.finaud-guyot@umontpellier.fr

1.1 Introduction

High Resolution (HR) flood risk mapping over large urban areas is increasingly needed. Applications range from real time flood risk management to urban development scenario appraisal [1]. The threat to lives and goods is a function of highly local factors, such as water depth, flow rate or the duration of exposition to floods [2]. Two-dimensional shallow water models are considered as a reference approach to the modelling of free surface flows in urban areas. However, the typical size of relevant hydraulic details in the urban environment is 0.1–1 m, which implies using a meshing density of 10^6 – 10^{10} computational points/cells/elements per square kilometer [3]. While the advent of HR data acquisition means makes geometry characterization increasingly easier [4], using HR models increases the required CPU time. The computational burden may be relieved by using so-called upscaled models, that operate over Low Resolution (LR) grids and provide CPU time gains over 2 to 3 orders of magnitude. In such models, the urban geometry is described in statistical terms, using areal or linear indicators such as porosities [5–7], building coverage ratios or conveyance reduction factors [8, 9]. The price to pay for the increased speed is the subsequent loss in the resolution of the hydraulic flow variables. As mentioned above, this is not compatible with the needs of detailed flood hazard mapping.

Therefore, some form of downscaling is required in order to retrieve HR flow fields or hazard indicators from LR ones. Downscaling is frequently used in the field of climatology and meteorology, see e.g. [10–12]. To our best knowledge, it has emerged only recently in the field of flood hazard mapping.

In [13], a local subgrid model was used to downscale the simulation results of a parallelized, upscaled model. In [14] a global downscaling method was proposed, whereby the HR solution is reconstructed over the entire computational domain using the LR solution over the entire computational domain too. Principal Component Analysis (PCA), also called Proper Orthogonal Decomposition (POD) [15], was used to reduce the complexity of the information in both the HR and LR solutions. The POD features of the HR solution were then downscaled from the POD features of the LR solution using an Artificial Neural Network (ANN). The structure and coefficients of the ANN were optimized by training the ANN over a set of (HR, LR) simulation couples.

This communication presents a local downscaling method that allows HR risk indicators (the water depth or the unit discharge vector) to be reconstructed from LR simulation results. The method is local in space and time, that is, the HR, downscaled variable at a given point of interest is reconstructed as a linear combination of the transformed LR variables in the cells surrounding this point. The proposed approach lies somewhere between [13] and [14] in terms of method complexity. As in [14], the feasibility of the approach is tested under the assumption of perfect upscaling. This paper is organized as follows. Section 1.2 gives an outline of the method, including the HR model, the LR one and the downscaling approach. Section 1.3 presents the results on two types of cases. The first is an idealized urban layout, over which the propagation of 1D flood waves is simulated. The purpose is to determine the amount

of training required by the method to achieve a given downscaling accuracy for different flow scenarios. The second test case is a field-scale application reported in [16]. Section 1.4 is devoted to concluding remarks.

1.2 Methods

1.2.1 Upscaling Versus Downscaling

Consider a domain of space Ω over which a HR model is available in the form of a system of differential equations:

$$\mathbf{L}_{\text{HR}}(\mathbf{u}_{\text{HR}}, \boldsymbol{\varphi}_{\text{HR}}) = 0 \quad (1.1)$$

where \mathbf{L}_{HR} is a differential operator, $\boldsymbol{\varphi}_{\text{HR}}$ is a vector containing the model parameters and \mathbf{u}_{HR} is the HR flow solution. Upscaling is understood as a filtering problem [17] whereby (1.1) is transformed into an equation in the form:

$$\mathbf{L}_{\text{LR}}(\mathbf{u}_{\text{LR}}, \boldsymbol{\varphi}_{\text{LR}}) = 0 \quad (1.2)$$

where the differential operator \mathbf{L}_{LR} , the solution \mathbf{u}_{LR} and the parameter vector $\boldsymbol{\varphi}_{\text{LR}}$ are defined over a LR space (and possibly time) grid. Downscaling is the reciprocal transformation, whereby (1.2) is used as a starting point to retrieve the elements of (1.1).

There is not a unique way of upscaling the flow model (1.1) into (1.2). Two main paths are available from the literature:

- (a) Parameter upscaling: $(\mathbf{L}_{\text{LR}}, \mathbf{u}_{\text{LR}}) = (\mathbf{L}_{\text{HR}}, \mathbf{u}_{\text{HR}})$, $\boldsymbol{\varphi}_{\text{LR}} \neq \boldsymbol{\varphi}_{\text{HR}}$. In this case, the governing equations and the flow variables are identical on both the LR and HR grids, only the parameter vectors are different. This is the case in e.g. groundwater flow modelling, when an equivalent macroscale hydraulic conductivity field is sought from a highly variable one on the microscale. Both HR and LR models use Darcy's flow equation, with the hydraulic head as a state variable, only the hydraulic conductivity differs from the HR to the LR model.
- (b) Model upscaling: $(\mathbf{L}_{\text{LR}}, \mathbf{u}_{\text{LR}}, \boldsymbol{\varphi}_{\text{LR}}) = (\mathbf{L}_{\text{HR}}, \mathbf{u}_{\text{HR}}, \boldsymbol{\varphi}_{\text{HR}})$. In this case, the LR and HR governing equations are different, they may operate on different flow variables and the parameters are usually different in both models. An example is that of the Navier–Stokes equations than can be upscaled into Darcy's flow equation using homogenization processes [18].

In the field of free surface flow, the model upscaling approach is the most widely used one, with porosity models and similar approaches [3, 5, 6, 8, 9, 16, 19]. Such

models are derived using volume averaging approaches [20] by defining:

$$\langle \mathbf{u} \rangle(\mathbf{x}, t) = \frac{1}{\mathbf{D}(\mathbf{x})} \int_{\mathbf{D}(\mathbf{x})} \mathbf{u}_{HR}(\mathbf{x}, t) d\mathbf{D} \quad (1.3)$$

where \mathbf{X} is the space coordinate and $\mathbf{D}(\mathbf{x})$ is an averaging domain centered around \mathbf{x} . In most finite volume implementations of porosity models, the averaging domain is the LR computational cell. The averaging domains thus form a partition of the solution domain. It should be stressed however that this approach is not the only possible one and that other filters than (1.2) may be used. If the upscaling is perfect, then the LR solution coincides with the exact average (1.3) of the HR variable at all points.

1.2.2 Problem Position

The HR model considered in the present work is the 2-Dimensional (2D) shallow water model:

$$\frac{\partial \mathbf{u}}{\partial t} + \frac{\partial \mathbf{f}}{\partial x} + \frac{\partial \mathbf{g}}{\partial y} = \mathbf{s} \quad (1.4a)$$

$$\mathbf{u} = \begin{bmatrix} h \\ q \\ r \end{bmatrix} \quad \mathbf{f} = \begin{bmatrix} q \\ \frac{q^2}{h} + \frac{1}{2}gh^2 \\ \frac{qr}{h} \end{bmatrix} \quad \mathbf{g} = \begin{bmatrix} r \\ \frac{qr}{h} \\ \frac{r^2}{h} + \frac{1}{2}gh^2 \end{bmatrix} \quad \mathbf{s} = \begin{bmatrix} 0 \\ gh(S_{0,x} - S_{f,x}) \\ gh(S_{0,y} - S_{f,y}) \end{bmatrix} \quad (1.4b)$$

where g is the gravitational acceleration, h , q , r are respectively the water depth and the x - and y - unit-discharges, $S_{0,X} = \partial z_b / \partial X$ and $S_{f,X}$ ($X = \{x, y\}$) are respectively the bottom and the energy slope in the X -direction. z_b is the bottom elevation and $S_{f,X}$ is calculated using the Manning formula:

$$S_{f,X} = n_X^2 (q^2 + r^2)^{1/2} u_X h^{-7/3} \quad (1.5)$$

where n_X (respectively u_X) is the Manning coefficient (respectively the velocity) in the X -direction. The shallow water model is solved using a classical explicit finite volume algorithm [21]. The upscaled solution is obtained from a perfect upscaling procedure, that is, by taking the LR upscaled variable equal to the average of the HR one over each cell of the finite volume LR grid:

$$\mathbf{u}_{LR}(\mathbf{x}, t) = \langle \mathbf{u} \rangle_i(\mathbf{x}, t) = \frac{1}{\Omega_i} \int_{\Omega_i} \mathbf{u}_{HR}(\mathbf{x}, t) d\Omega_i \quad \text{for } \mathbf{x} \in \Omega_i \quad (1.6)$$

where Ω_i is the i th computational cell in the model.

The objective of the present work is to derive HR flood hazard indicators using only the LR solution defined by Eq. (1.6). The flood hazard indicators retained in the present study are the same as in [14]: the water depth and the norm of the unit discharge are considered as two widespread danger indicators [22] [23]. A hazard variable vector $\boldsymbol{\psi} = [h, \boldsymbol{\theta}]^T = \boldsymbol{\psi}(\mathbf{u})$ is thus defined as in [14], where $\mathbf{q} = [q, r]^T$ is the unit discharge vector. The purpose is thus to derive the HR hazard indicator from the LR one. Note that Eq. (1.6) cannot be applied directly to the norm of the unit discharge because the norm of the unit discharge is not a conserved variable. The following formula is used instead:

$$\mathbf{q}_{LR} = (q_{LR}^2 + r_{LR}^2)^{1/2} \quad (1.7)$$

where q_{LR} and r_{LR} are computed using (1.6).

1.2.3 Proposed Downscaling Approach

The proposed downscaling formulae are based on the following principle. Assume that the k th component $\psi_{HR}^{(k)}$ of the HR hazard variable vector $\boldsymbol{\psi}$ is sought at the location \mathbf{x} at time t . It is computed using the LR hazard variables over a limited number of cells of the LR mesh. Let $\psi_{LRi}^{(k)}$ be the value of the k th component of the LR hazard variable (here $k = 1, 2$) over the i th cell of the LR grid. Denoting by N_k the set of neighbouring LR cells used in the downscaling reconstruction, the following linear combination is proposed:

$$\left(\psi_{HR}^{(k)}\right)^{p_k}(x, t) = \sum_{i \in N_k} \alpha_i^{(k)} \left(\psi_{LRi}^{(k)}\right)^{p_k} \quad (1.8a)$$

$$N_k = N_k(\mathbf{x}), p_k = p_k(\mathbf{x}), \alpha_i^{(k)} = \alpha_i^{(k)}(\mathbf{x}) \quad (1.8b)$$

where p_k is a positive power performing a non-linear transformation and the $\alpha_i^{(k)}$ are weights. As specified by Eq. (1.8b), the size of the neighbourhood (i.e. the set of LR cells used to reconstruct the HR risk indicator), the weights and the power in the reconstruction formula are all functions of the hazard variable to be reconstructed (for instance reconstructing h does not necessarily require the same number of cells as reconstructing \mathbf{q}). Moreover, they also depend on the location \mathbf{x} of the HR hazard variable to be reconstructed. The degrees of freedom in the formula are the size $N_k(\mathbf{x})$ of the neighbourhood, the $N_k(\mathbf{x})$ weights and the power $p_k(\mathbf{x})$.

The optimal values for these $N_k(\mathbf{x}) + 2$ degrees of freedom are found by minimizing the difference (i.e. the modelling error) between the reconstructed hazard variable $\psi_{HR}^{(k)}$ and its exact value $\psi^{(k)}(\mathbf{u}_{HR})$ computed from the known HR variable

\mathbf{u}_{HR} . The error for the k th component of the hazard indicator vector is thus location-dependent. Its root mean squared average over time is the objective function to be minimized via the optimization procedure:

$$E^{(k)}(\mathbf{x}) = \left(\frac{1}{T} \int_0^T \left(\psi_{HR}^{(k)}(\mathbf{x}, t) - \psi^{(k)}(\mathbf{u}_{HR}(\mathbf{x}, t)) \right)^2 dt \right)^{1/2} \quad (1.9)$$

where $[0, T]$ is the time interval.

1.2.4 Training Sequence

Prior to training, a number of HR simulations with various combinations of initial and boundary conditions are carried out over a given computational domain Ω over a time interval $[0, T]$. For each simulation, an HR solution $\mathbf{u}_{HR}(\mathbf{x}, t)$ is thus available over the $\Omega \times [0, T]$ space–time domain. Each HR solution is averaged into a LR solution $\mathbf{u}_{LR}(\mathbf{x}, t)$ over a coarse grid using Eq. (1.6). Therefore, for every simulation, a pair $(\Psi_{HR}(\mathbf{x}, t), \Psi_{LR}(\mathbf{x}, t))$ of HR and LR hazard vectors is available over $\Omega \times [0, T]$. These are divided into three sets (Fig. 1.1): a calibration, validation and training sets, the roles of which are detailed hereafter.

The model operation sequence is the following.

Step 1: For each HR hazard variable to be reconstructed at a given location \mathbf{x} , a number of possible neighbourhood sizes are proposed.

Substep 1.1 (calibration): for every neighbourhood size, the reconstruction formula (1.8a) is calibrated by minimizing the error given by Equation (1.9).

Substep 1.2 (validation): for each neighbourhood size, the calibrated reconstruction formula (1.8a) is run over the validation set. The validation performance is evaluated by computing the modelling error as in Eq. (1.9).

Step 2 (operational use): The neighbourhood size N_k that gives the smallest validation error is retained.

Substep 2.1: the coefficients $(p_k, \alpha_i^{(k)})$ are calibrated again using both the calibration and validation sets.

Substep 2.2: the predictive performance of the model is evaluated using the modelling error as given by Eq. (1.9).

1.3 Results

The proposed downscaling approach is tested on two different configurations: a synthetic urban layout and a real-world test case.

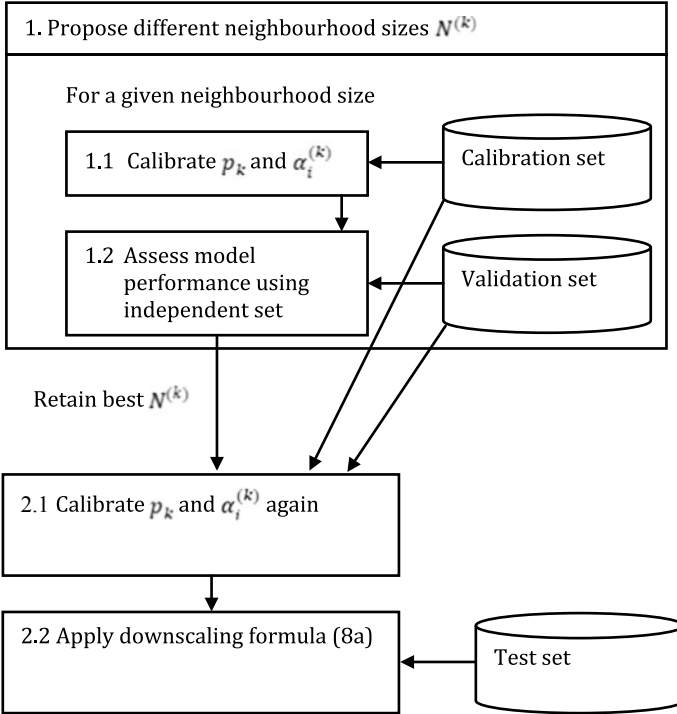


Fig. 1.1 Definition sketch for method training and testing

1.3.1 Idealized Urban Layout

1.3.1.1 Test Case Description

An idealized urban layout configuration is used to assess the ability of the proposed downscaling approach to reconstruct the hydrodynamic variables with a high resolution using the low-resolution results. The geometry is made of a main street bounded by dead-end lateral streets (see Fig. 1.2). The reconstruction method is tested over three crossroads at the middle of the main street and close to the upstream and downstream end.

In the present paper, the bottom elevation is horizontal and the friction is neglected for all the tested configurations. Initially, the water surface elevation z_0 is constant and the velocity is nil over the whole domain. At $t = 0$, the free surface elevation at the left (respectively right) boundary condition is set to z_L (respectively z_R), the other one being kept to z_0 . The free surface elevation at the “perturbed” boundary conditions is denoted z_{BC} (correspond to z_L or z_R depending on the test case). This allows to generate different types of waves (rarefaction if $z_{BC} < z_0$; shock if $z_{BC} > z_0$) travelling through the domain from the left to the right boundary conditions (and

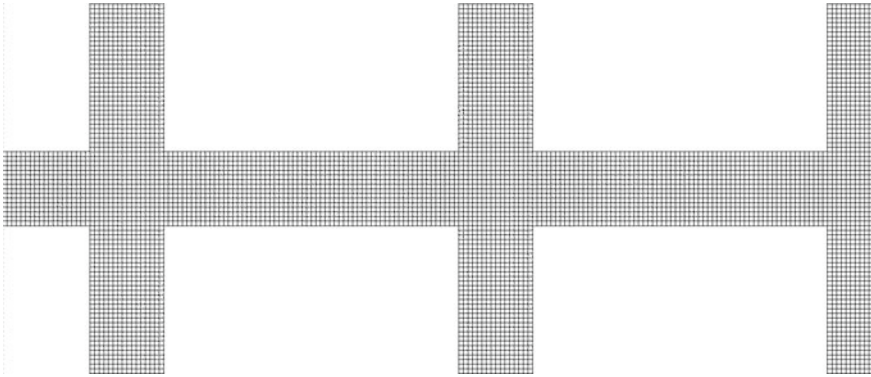


Fig. 1.2 Representation of the idealized urban layout. The represented mesh is the fine one. For the sake of readability, only 3 crossroads over 20 are represented

inversely). The different configurations are summarized in the Fig. 1.3. The triangles (respectively the diamonds) represent the simulation defining the calibration (respectively validation) set. The hydraulic configurations for the test simulations (represented by the circles) are located outside the range of the training domain. The simulation naming is composed of two letters: the first one represents the wave configuration (S for shock wave, R for rarefaction wave); the second letter identifies boundary/initial conditions combination. Simulations a–j (respectively k–t) represent waves travelling from left to right (respectively right to left). The proposed down-scaling method is expected to be able to reconstruct the hydrodynamic variables from the LR results on the fine grid including for hydraulic configurations beyond the training domain.

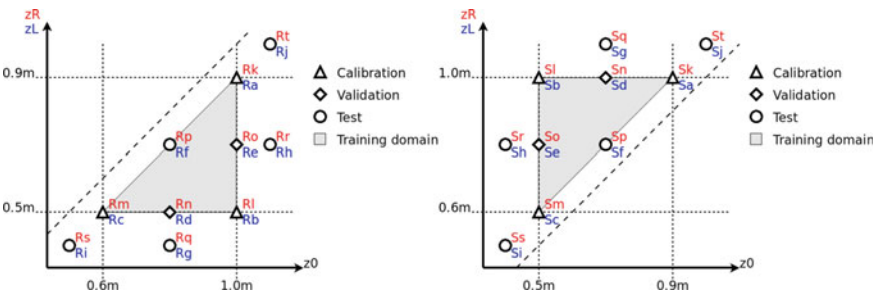


Fig. 1.3 Representation of the tested hydraulic configurations. Left: rarefaction wave, Right: shock wave

1.3.1.2 Influence of the Wave Configuration

This test case investigates the variability of the wave configuration (either shock or rarefaction) that should be represented in the learning set to allow a correct downscaling in any wave configuration. For the sake of simplicity, the considered configurations represent only waves from the left to the right side. Three different combinations of the simulations between the different sets are compared (see Table 1.1). The test set 1 includes hydraulic configurations corresponding to the learning set whereas test set 2 regroups voluntarily “unknown” hydraulics configurations as they were not represented in the learning set. The reconstructed results are expected to be closer from the reference for test Set 1. Test set 2 allows to assess the importance of having a learning set that is as exhaustive as possible.

Figure 1.4 presents the size of the optimal neighbourhood to reconstruct the water depth for combinations R and S. It is recalled that the tested neighbourhood sizes are $N(i) = \{3, 5, 7, 9, 11\}$. The optimal neighbourhood size appears to be smaller when the simulations combination includes shock wave. Smaller neighbourhood is coherent with the discontinuities that appears in case of shock waves. Interestingly, the wave configuration appears to have no significant impact on the optimal neighbourhood size to reconstruct the unit-discharge norm. The optimal size of the neighbourhood also evolves along the street axis. In all the tested configurations, the simulation duration allows the wave to travel through the three represented crossroads. However, the reconstruction coefficients are constant in time. This implies

Table 1.1 Tested repartitions of the simulations to investigate the influence of the wave configuration

Combination	Calibration set	Validation set	Test set 1	Test set 2
Comb. R	Ra Rb Rc	Rd Re	Rf Rg Rh Ri Rj	Sf Sg Sh Si Sj
Comb. S	Sa Sb Sc	Sd Se	Sf Sg Sh Si Sj	Rf Rg Rh Ri Rj
Comb. R + S	Ra Rb Rc Sa Sb Sc	Rd Re Sd Se	Rf Rg Rh Ri Rj Sf Sg Sh Si Sj	

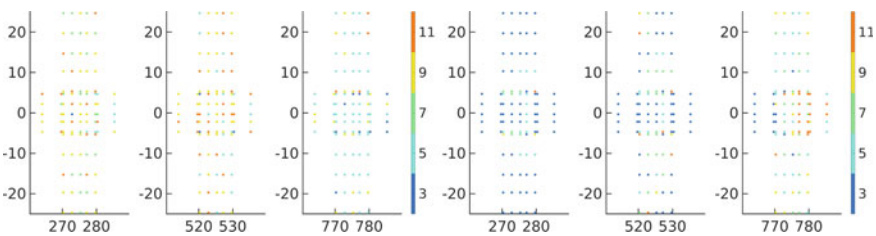


Fig. 1.4 Distribution of the optimal neighbourhood size to reconstruct the water depth. Left: Combination R; Right: combination S. The graphs axis represents the spatial coordinate: the crossroad around the coordinate 275 m (respectively 525 m and 775 m) is the 6th (respectively 11th and 16th) crossroad after the beginning of the model (see Fig. 1.2)