

Computer Modelling Techniques in Environmental Hydraulics and Water Resource Engineering

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1. Introduction

Computer modelling has become indispensable to environmental hydraulics and water resource engineering, where researchers and practitioners are increasingly required to analyse complex and dynamic water systems across a wide range of spatial and temporal scales. From hydraulic structures to water quality, catchment hydrology, and water resource planning, computer models provide the basis for understanding physical processes, testing management strategies, and supporting engineering decision-making under uncertainties [1,2]. As environmental pressures intensify due to climate change, growing human intervention, and increasing demands on water systems, the role of computational modelling has become both broader and more critical [3].

At the same time, the methodological landscape of water modelling is evolving rapidly. Physics-based modelling remains fundamental for faithfully representing hydraulic and hydrological mechanisms, loyally resolving flow and transport processes, and straightforwardly maintaining interpretability [4]. However, conventional modelling approaches are now increasingly complemented by optimisation techniques, uncertainty analyses, and data-driven methods, particularly in situations characterised by sparse observations, high system complexity, and the necessity for timely operational predictions [5]. Rather than replacing physics-based approaches, these emerging methods are reshaping the field towards integrated computational frameworks in which mechanistic understanding, statistical inference, and algorithmic efficiency are considered in a complementary manner [6].

This Special Issue, “Computer Modelling Techniques in Environmental Hydraulics and Water Resource Engineering”, reflects the aforementioned transition clearly. It focuses on mathematical modelling and numerical simulations in environmental hydraulics and water resource engineering, while also encouraging the integration of artificial intelligence (AI) into conventional computational modelling. The papers collected in this Special Issue provide a timely overview of current advances in the field, spanning process-based hydraulic and water-quality modelling, optimisation and infrastructure designs, data-driven forecasting, uncertainty analyses, and evidence syntheses. Taken together, these contributions show that contemporary water modelling is becoming more computationally sophisticated, more integrated, more adaptive, and more closely relevant to decision-making.



Received: 7 April 2026

Accepted: 27 April 2026

Published: 7 May 2026

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2. Contributions in the Special Issue

The twelve papers collected in this Special Issue illustrate the breadth and diversity of the current modelling research in environmental hydraulics and water resource engineering. The contributions range from hydraulic process simulations and water-quality analyses to optimisation, infrastructure planning, risk assessment, data-driven prediction, and critical review. Despite this diversity, they are linked by a common objective: to advance the use of computational modelling for better understanding, prediction, and management of water systems under increasingly complex and changing environmental conditions.

Zhuang et al. [contribution 1] provide a timely and valuable review of the flood-mitigation performance and numerical representation of leaky barriers. The paper synthesises the recent field evidence, hydraulic parameterisation strategies, and modelling approaches with impressive clarity, while also identifying persistent data and methodological gaps; as such, it offers a strong reference point for both researchers and practitioners working on nature-based flood management.

Toro et al. [contribution 2] investigate the influence of roughness height on turbulence statistics in non-aerated skimming flow regions over steep-stepped spillways. Using numerical simulations validated against experimental data, the study demonstrates that appropriately rescaled turbulence quantities exhibit notable self-similar behaviour across different roughness heights, providing insights into the distinct physics and suitable models for stepped-spillway flows.

Koue [contribution 3] investigates the dependence of flow patterns on the nutrient release from sediments and density variations driven by organic matter in enclosed water bodies. By coupling hydrodynamic and ecosystem modelling, the study offers a valuable mechanistic explanation of how density currents, plume development, and compensatory circulation can redistribute nutrients and organic matters, thereby enriching our understanding of internal water-quality deterioration processes in stratified systems.

Wu et al. [contribution 4] conduct a detailed sensitivity analysis of the dissolved oxygen in a cold-region river using a calibrated water-quality model with ice effects implemented in MIKE HYDRO River. The study is particularly commendable for showing that all 14 biologically related parameters remain highly influential even under winter ice conditions, and a distinct seasonal pattern was observed for most parameters. This study provides both modelling insight and practical guidance for water-quality assessment in cold environments where observations are limited.

Tian et al. [contribution 5] present a well-executed optimisation study of a non-pressurised tunnel intersection in a pumped-storage power station. Combining scaled hydraulic experiments with three-dimensional numerical modelling, the paper shows convincingly how geometric refinement can reduce the level of turbulence, control water-surface elevations, and ensure compliance with specifications, making it a valuable contribution to hydraulic structure design.

Liu et al. [contribution 6] analyse the variation in actual evapotranspiration (ET) and the uncertainty of its response to local climate change in an arid inland basin. By combining water-balance analysis, regression modelling, Copula-based joint distributions, and Monte Carlo simulation, the study provides a rigorous and carefully structured treatment of climate-driven ET uncertainty, with clear relevance for water resource assessment in arid regions.

Hu et al. [contribution 7] develop an ecological well-being model for water-saving planning in an arid irrigation district of northwest China. The paper is notable for moving beyond a purely engineering view of water saving, instead embedding ecological thresholds, groundwater constraints, and management scenarios into an inte-

grated planning framework, offering a thoughtful and well-rounded model for sustainable irrigation management.

Kepa and Deska [contribution 8] demonstrate how a calibrated EPANET hydraulic model can support the conceptual planning of rural water-supply network reconstruction. Their case study focuses on the introduction of new water intakes, identifying their required capacity and optimal locations. The obtained results illustrate how hydraulic simulations can diagnose instability, compare infrastructure options, and guide robust investment decisions in small and operationally constrained water systems.

Kuhaneswaran et al. [contribution 9] present a systematic mapping study of data-driven flood forecasting studies from 2019 to 2024. This review critically identifies prevailing algorithmic preferences, geographical disparities, and missed opportunities. It also provides researchers and practitioners with actionable insights into the methodological practices and future directions in data-driven flood forecasting, thereby advancing the critical field for disaster management.

Najaftomaraei et al. [contribution 10] explore AI-based optimisation of renewable-powered reverse-osmosis desalination systems. Their multi-objective optimisation framework is built around the Non-dominated Sorting Genetic Algorithm II (NSGA-II) and applied to photovoltaic (PV) panels and wind turbines (WTs). The results demonstrate that hybrid renewable systems can significantly reduce grid dependence while improving energy stability by leveraging the complementary nature of PV panels and WTs.

Li et al. [contribution 11] propose a Copula Bayesian Network framework for analysing operational safety risks in long-distance water-diversion projects. The study deserves praise for incorporating risk correlation analyses, Bayesian reasoning, and dynamic inference into a coherent decision-support framework, and for demonstrating its practical value through an application to the Middle Route Project of the South-to-North Water Diversion Project.

Gao et al. [contribution 12] investigate streamflow forecasting in data-scarce catchments through similarity-guided source selection and transfer learning. The paper makes an important discovery by showing that carefully selected, hydrologically similar source basins can outperform indiscriminate large-sample pre-training, thereby advancing both the efficiency and the interpretability of transfer-learning strategies in hydrological predictions.

3. Conclusions and Future Perspectives

The papers collected in this Special Issue demonstrate that computer models in environmental hydraulics and water resource engineering are rapidly evolving in both scope and capability. Physics-based numerical models remain indispensable for resolving flow behaviour, hydraulic controls, environmental transport, and infrastructure performance. At the same time, optimisation-based and data-driven approaches are expanding the analytical toolbox available to researchers and practitioners. A particularly important message emerging from this collection is that physical modelling and AI should not be viewed as competing and exclusive paradigms. Rather, these papers point to a trend towards model integration. Process-based models are increasingly being coupled with a range of advanced optimisation strategies. When data-driven methods are applied to improve forecasting and decision support, more attention has been paid to uncertainty, transferability, and practical usefulness.

Looking ahead, the following three broad priorities appear especially important. First, greater progress is likely to stem from hybrid modelling frameworks that combine physical understanding with machine learning, optimisation, and data assimilation, rather than from reliance on monotonic modelling philosophy. Second, model development should place stronger emphasis not only on predictive ability, but also on interpretability, uncertainty quantification, and transferability across sites and cases. Third, the value of

modelling research will increasingly be judged by its operational and policy relevance: models must not only simulate water systems credibly, but also support planning, risk management, infrastructure design, and sustainable resource governance under rapidly changing environmental conditions.

Overall, this Special Issue offers a concise yet representative picture of contemporary computer modelling techniques in environmental hydraulics and water resource engineering. It highlights the continuing strength of process-based computation, the rapid growth of AI-based methods, and the increasing need for integrated approaches that are physically informed, data-aware, and practically useful. We hope that the contributions gathered here will stimulate further methodological innovations and strengthen the links among modelling research, engineering practice, and sustainable water management.

Author Contributions: Conceptualisation, H.H., Y.S. and D.L.; resources, H.H., Y.S. and D.L.; writing—original draft preparation, H.H., Y.S. and D.L.; writing—review and editing, H.H. and D.L.; project administration, H.H. and Y.S.; funding acquisition, H.H. and Y.S. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: As Guest Editors of the Special Issue “Computer Modelling Techniques in Environmental Hydraulics and Water Resource Engineering”, we sincerely thank all contributing authors for their valuable research and all the reviewers for their insightful feedback. We are grateful to the Central Government Guidance for Local Science and Technology Development Funds Project of Henan Province (No. Z20241471035) and Key R&D Program of Henan Province (No. 24111210300).

Conflicts of Interest: The authors declare no conflicts of interest.

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