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Editorial

Advances in Flow Modeling for Water Resources and Hydrological Engineering

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Abstract: Surface and ground waters can be considered the main sources of water supply for agricultural, municipal, and industrial consumers. Over the centuries, the combination of both naturally occurring conditions and humanity's actions has placed increasing pressure on these water resources. As an example, climate change and natural variability in the distribution and occurrence of water are among the natural driving forces that complicate the sustainable development of water resources. Recent advances in computer techniques have allowed scientists to develop complex models at different scales to support water-resource planning and management. The Special Issue "Advances in Flow Modeling for Water Resources and Hydrological Engineering" presents a collection of scientific contributions providing a sample of the state-of-the-art research in this field.

Keywords: water resources modelling; flood forecast; climate-change impacts; drought; river quality; river morphology; watershed hydrology; watershed management; reservoir management

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Citation: Costanzo, C.; Padulano, R.; Caloiero, T. Advances in Flow Modeling for Water Resources and Hydrological Engineering. *Hydrology* **2022**, *9*, 228. https://doi.org/10.3390/hydrology9120228

Received: 9 November 2022
Accepted: 23 November 2022
Published: 19 December 2022

1. Introduction

Water resource systems planning and management issues are often very complex. The pressures on water resources are increasing with the expansion of global development, involving ecological and hydrological consequences in river basins and groundwater aquifers and water-quality deterioration. All this leads to the growing need to investigate the effects of different human influences and impacts on the hydrological regime and water quality, such as land-use changes, climatic variability and climate change, and intensified water and land-use practices. Moreover, economic, environmental, and social issues have gained considerable attention in water resources research. In this context, computer-based models can help to choose the most impactful plans, designs and policies. Over the last few years, advances in computer techniques have allowed scientists to develop complex models at different scales to support water resource planning and management.

The Special Issue "Advances in Flow Modeling for Water Resources and Hydrological Engineering" focuses on recent advances in models and methods for water resource modelling. In particular, the following issues have been discussed: basin-wide water resources planning; watershed management; flood forecasting; droughts; climate change impacts on flood risk and water resources; reservoir operation and management; river morphology and sediment transport; river-water quality.

2. Some Data of the Special Issue

From early December 2019 to late September 2022, a total of 36 papers were submitted to this Special Issue. After a rigorous editorial check and peer-review process, involving external and independent experts in the field, 15 papers were rejected and 21 papers were accepted (about 57%). Of the 21 articles published in the Special Issue, 1 is a Technical

Note [1], and 20 are Research Articles [2–21]. Figure 1 compares the geographic distribution of the first authors of the research teams publishing in the Special Issue (Figure 1a), as well as that of the case studies and demonstration sites (Figure 1b). The analysis of this figure allows one an overview of the scientific community working on flow modelling for water resources and hydrological engineering, although it is just a sample and thus not an exhaustive representation. Seventy-nine authors from five different continents (Africa, America, Asia, Europe and Oceania) contributed to the Special Issue, showing the results of case studies and demonstration sites from the same five continents.

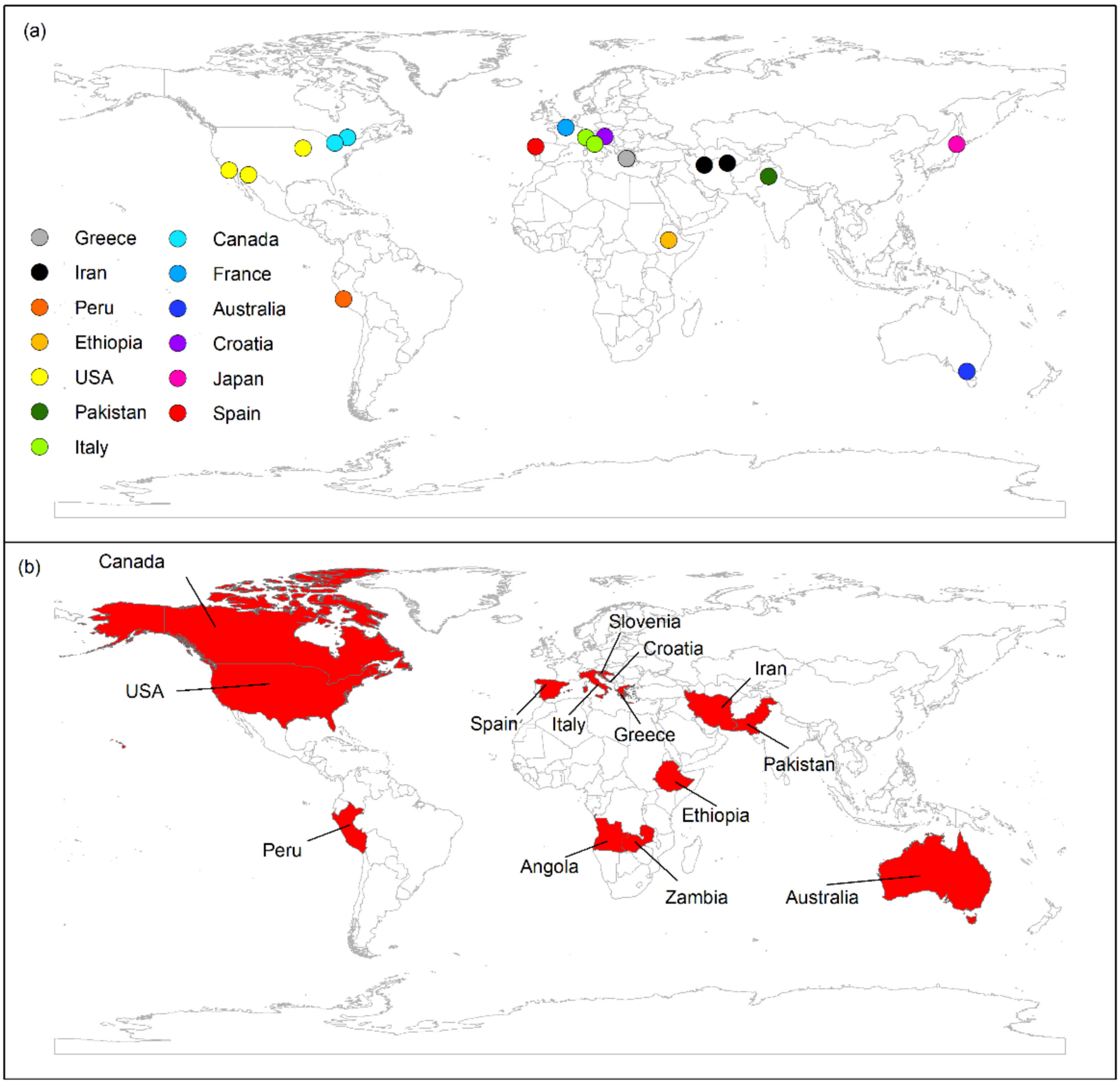

Figure 1. Geographic distribution of (**a**) first authors of research teams publishing in the Special Issue; (**b**) case studies and demonstration sites that are discussed in the papers.

Figure 2 shows the main keywords of the papers in Special Issue, which reflect the scope of scientific content on the subject. The relevant themes are numerous, ranging from hydraulic laws to hydraulic numerical models, to climate change, to hydrological models and forecasting models. All these themes refer to applications to experimental cases or actual rivers or catchment areas. "Modelling" is the predominant keyword, cited in 5 out of 20 articles, among which three referred to "Hydrological Modelling".

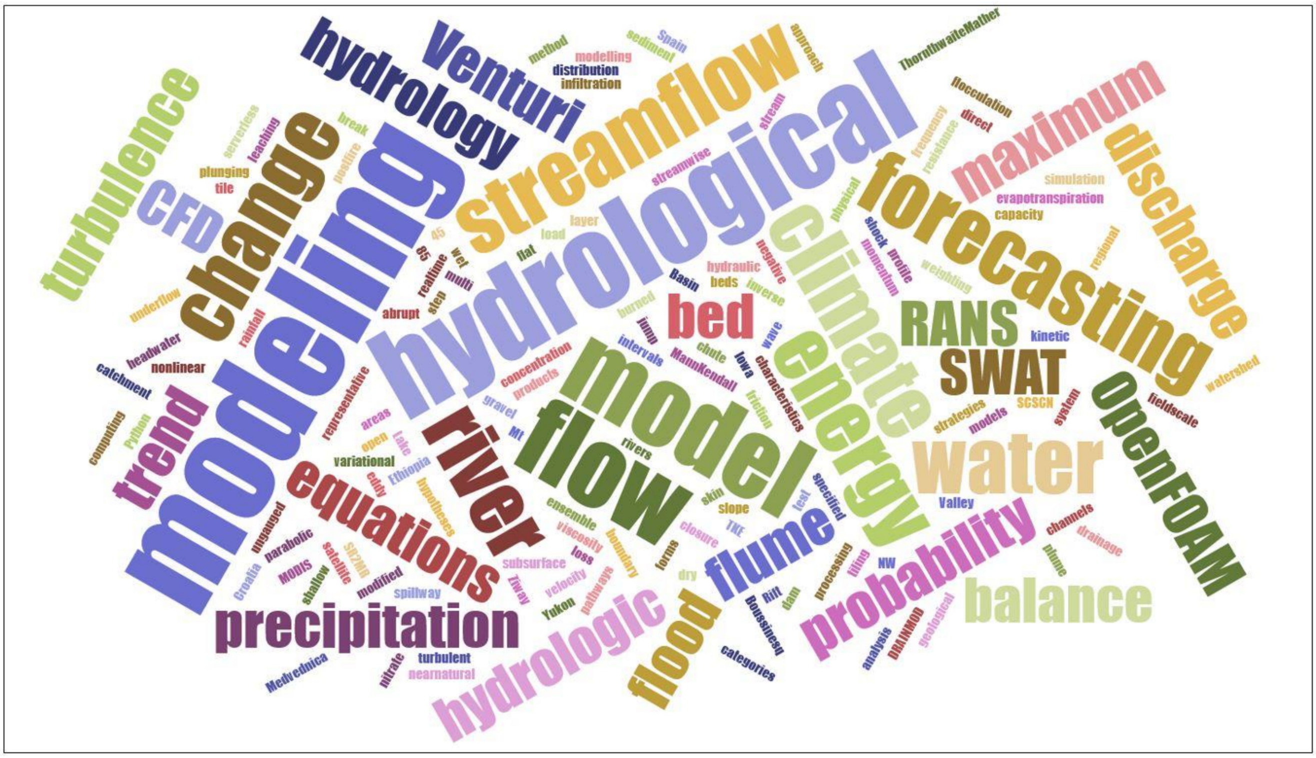

Figure 2. Word cloud of the keywords published in the Special Issue.

3. Overview of the Special Issue Contributions

The paper [1] presents a web app for a rapid, smart and smooth computation of catchment-scale water balance, relying on the Thornthwaite–Mather method, which only requires simple input information such as temperature, precipitation and location of the site. By properly setting, or possibly calibrating, input parameters such as the runoff coefficient, flow values are simulated, and they can be compared to observed values for validation. The app is tested on two different catchments: one in Northern Italy and the other in Slovenia, with different performances due to the underestimation of snowfall and snow melting in the latter.

Paper [2] presents an in-depth trend analysis of the main hydro-climatic variables (rainfall, temperature, low and high flows) recorded in the headwaters of the Mero catchment (NW Spain). The case study is a near-natural regime stream, negligibly influenced or modified by human activities, and it is particularly significant in terms of water resources for the nearby area. The study detected statistically significant trends in mean seasonal stream discharge for autumn and summer. In addition, a significant upward trend in the number of days with low flow was particularly evident in spring and summer. Additionally, a falling trend in high flows was observed in autumn. Such trends often proved to be inconsistent with rainfall trends: however, this behaviour can be explained by also accounting for temperature trends.

In paper [3], the authors address the possible role of climate change in altering groundwater quality in terms of tile drainage and consequent nitrogen yield, using a test case located in the Great Lakes area (Canada). A well-known field-scale model, DRAINMOD, is calibrated, relying on literature parameters and site observations for rainfall and temperature, and then applied to climate projections under a future emission scenario. Tile flow is estimated to increase, especially in winter; however, the projected rise in nitrate loss through tiles was uncorrelated with tile flow. This could be explained by an increase in minimum spring temperature, leading to enhanced nitrification and excessive nitrate loss.

The goal of paper [4] is to assess the potentialities and limitations of CFD models in simulating the performance of the Parshall flume, a variation on the Venturi flume often used to collect laboratory and field discharge data. By using OpenFOAM, which is associated with seven different turbulence models, a selection of geometries for the Parshall flume are numerically set up, and numerical results are compared to the measured data collected in corresponding experimental scenarios. Results show that, although their performances vary, all the tested turbulence models are able to satisfactorily capture the actual flow in the flume. However, additional tests are recommended to further explore the range of simulated discharge values.

In paper [5], the estuarine area of the Yukon River (Alaska) is analysed with particular reference to the surface sediment plumes formed by glacier-melt and rainfall sediment runoff, with the aim of exploring the mechanisms behind plume plunging at the boundary between river water and marine water. Analysis relies on discharge and sediment measurements, as well as on plume observations conducted from a boat. It was found that both the suspended sediment concentration and sediment load of the Yukon River were relatively high in the glacier-melt and rainfall runoffs of July-September. Hence, temporal variations of glacier-melt and rainfall could change the behavior of the sediment plume in the coastal region.

The goal of paper [6] is to set up a flood prediction model based on the concept of "Probability of Success". The model, developed for the Croatian catchment referring to the Gornja Kašina hydrological station, assesses the probability of flooding as the overlap of five statistical categories describing the most relevant factors affecting the rainfall–runoff transformation (climatological, geological and geographical features). Comparison with past flood observations for the test case showed that the model could capture flood events that caused significant damages, although they were not registered as "floods" by the involved stream gauges.

In paper [7], a real-scale dam-break wave was simulated using the 2D finite volume Roe-TVD method. For this purpose, a numerical code was developed to solve the 2D depth average, shallow water equations on unstructured triangular cells considering turbulence terms and a dry bed front. To validate the code, initially, available experimental data were considered. After verifying the model, the real-scale dam break was simulated, and the flow behaviour from encountering the two bridges was analysed along the pathway. The flood wave arrival time to the bridges, the flooded area and the duration of flooding of the bridges were studied.

Paper [8] aims to provide an explanation and a theoretical foundation for the empirical well-known eddy viscosity profiles. The eddy viscosity is defined as a product between a velocity scale and a length scale. From this definition, two analytical eddy viscosity models are proposed. The proposed analytical models are validated through the computation of velocity profiles, obtained from the resolution of the momentum equation, and comparison with experimental data.

In paper [9], the spatial variability of the main water balance components in an intensively agricultural area in the headwaters of Upper East Fork White River in Indiana, USA, was analysed. Extensive data collection was necessary to provide the best possible input for a SWAT model set up for the simulation. To optimise the data outputs, a spatial calibration approach was implemented in four gauging sites. It was confirmed that in areas with intensified agricultural development—an activity that heavily disturbs the land phase of the hydrological cycle—it is critical for hydrological models to incorporate factors such as water use and relevant agricultural management practices.

The authors of paper [10] use a computational fluid dynamics (CFD) approach to simulate flows in Parshall flumes, which are used to measure flowrates in channels. The objective of this research was to study the reliability of numerical simulations of a Parshall flume using various nonlinear turbulence models. The numerical results are compared with the experimental data, which show that choosing the right turbulence model is the key element in accurately simulating Parshall flumes.

Paper [11] aims to develop a robust and rational methodology to assess the change in the hydrological response of a post-fire watershed, especially where the scarcity or absence of hydrometric data do not allow the calibration of a more complex rainfall–runoff model. Thus, this study proposes an integrated approach that combines spatial information on burned areas and levels of fire severity, direct soil infiltration measurements and rainfall–runoff modelling. This approach was applied to a burned forest catchment in Italy to explain the repercussions of fire on the hydrological response of a natural watershed. Flood peak and volume were computed through the application of the Soil Conservation Service-Curve Number method (SCS-CN); the flow propagation was simulated through a lag-time approach based on the time–area curve of the catchment.

Paper [12] presents the physical model study of shock waves at the Mohmand Dam Spillway project in Pakistan. In this study, a hydraulic analysis of shock waves was carried out to investigate its generation mechanism. Different experiments were performed to analyse the rooster tail on a flat spillway chute and to examine the factors affecting the characteristics of the rooster tail. The results revealed that shock wave height is influenced by spillway chute slope, pier shape and flow depth. Moreover, the height of the shock wave can be minimized by installing a semi-elliptical pier on the tail part of the main pier.

Paper [13] evaluates the potential for a newly proposed nonlinear subsurface flux equation to improve the performance of the hydrological Hillslope Link Model. The equation contains parameters that are functionally related to the hillslope steepness and the presence of tile drainage. To assess performance improvements, they compare simulation results to streamflow observations during a 17-year period (2002–2018) at 140 U.S. Geological Survey (USGS) gauging stations. The new equation provides a better representation of hydrograph recession curves, hydrograph timing and total runoff volume. However, the authors found discrepancies in the spatial distribution of hillslope scale parameters.

Paper [14] describes the main stages and processes required to implement and improve an operational hydrologic forecasting system in the Upper Zambezi River Basin and its sub-basins. The process of implementation was complex, and several decisions needed to be made about the input data (precipitation from satellites or climate products), the hydrological models to be included along with their optimal parameter sets and the timescales required for the generation of streamflow forecasts. Once the system was completely operational, additional developments were required to improve its performance and reduce the spread of total hydrologic uncertainty into the final streamflow forecast products.

Paper [15] assesses historical (1983–2005) and future (2026–2100) rainfall, maximum temperature and minimum temperature trends in the Ziway Lake Basin (Ethiopia). Simulated historical and future climate data were obtained from the CMIP5 datasets considering the RCP4.5 and RCP8.5 emission scenarios. The modified Mann–Kendall trend test was applied to estimate the trends of annual rainfall, Tmax and Tmin in historical and future periods. Rainfall experienced no clear trends, while Tmax, and Tmin significantly increased in both RCP 4.5 and 8.5 scenarios, especially in the central part of the basin at the end of the 21st century.

In paper [16], the potential effects of climate change and variability on the maximum precipitation, temperature and hydrological regime in Devil's Creek, Tacna, Peru were analyzed. For this purpose, the outputs of the meteorological variables of fifteen regional climate models were used as inputs for the hydrological model considering the RCP4.5 and RCP8.5 emission scenarios. The results showed an increase in the maximum annual precipitation by more than 30% for both the RCP4.5 and RCP8.5 scenarios for the 2021–2050 period with reference to the 1981–2005 period. Moreover, the maximum flows could increase by 220% and 154% for the RCP4.5 scenarios for the 2021–2050 and 2051–2080 terms, respectively, and 234% and 484% for the RCP8.5 scenarios and for the 2021–2050 and 2051–2080 terms, respectively.

The aim of paper [17] is to develop a modified model that improves the accuracy of the determination of skin friction factors in gravel-bed rivers. With this aim, 100 velocity profile data obtained from eight gravel-bed rivers were utilized to develop an analytical method that considers the momentum thickness of the boundary layer and its deviation in large-scale topographic bedforms in a 1D force-balance model. The proposed model showed high accuracy in the prediction of skin friction factors for energy slopes between 0.001 and 0.1. Additionally, the model was used to modify the classic Einstein–Strickler equation, allowing an improvement of the accuracy of the predicted skin friction factors in nonuniform flow conditions even when velocity profiles and energy slope were unavailable.

In paper [18], the transition from supercritical to subcritical flow around a fully submerged abrupt negative step in a horizontal rectangular open channel was investigated in a laboratory experiment. As a result, five different types of rapidly varying flow were observed by varying the subcritical downstream tailwater depth. Moreover, the numerical results showed that the Boussinesq equations can simulate the basic flow characteristics with acceptable accuracy.

In paper [19], monthly streamflow and satellite-based actual evapotranspiration data (AET) were used to evaluate the Soil and Water Assessment Tool (SWAT) model for the calibration of an experimental sub-basin with mixed land-use characteristics in Athens, Greece. Three calibration scenarios were conducted with streamflow, AET and streamflow–AET data to evaluate the simulated outputs. The sensitivity analysis showed that the most sensitive parameters for streamflow are related to groundwater flow, runoff generation and channel routing, and for actual evapotranspiration, they are all connected to soil properties. This research showed that combining streamflow and MODIS satellite-based AET data in the calibration process can improve model performance regarding streamflow and water balance and contribute to understanding the hydrological processes in a mixed land-use catchment.

Paper [20] tests the suitability of the RFFE approaches within smaller headwater catchments in the Pilbara (Australia) and evaluates them through a comparison of peak discharge values derived from a 2D hydrodynamic direct rainfall model. This paper provides the first comparative study of The RFFE approaches for the Pilbara using updated ARR values to validate their use within smaller catchments in the same region.

Paper [21] deals with how the Colorado River may respond to future climates. Historical and future streamflow projections for the Colorado River basin were evaluated with a perspective of drought and surplus periods.

4. Conclusions

This Special Issue on numerical methods and models for water resource modelling is very interesting and constitutes a point of reference for future developments on the topic.

In particular, the Special Issue illustrates that the use of hydraulic models can assist with hydraulic constructions for planning the negative effects of shock waves on spillway operations [12], to determine the best combination of different turbulence models to design Parshall flumes [4,10], to model the eddy viscosity in surface flows [8], to determine hazard maps downstream of a dam [7] and to improve the accuracy of the determination of skin friction factors in gravel-bed rivers [17] and the performance of the hydrological Hillslope Link Model [13].

Similarly, the presented hydrological models contribute to future development regarding the study of the hydrological response after a fire [11], environmental sustainability ensuring socioeconomic stability and the production of critical crops in agriculture [9] and to determine the peak flow through regionalization techniques [20]. Significant attention is paid to the impacts of climate change on the performance of hydrological models in terms of water quantity and quality, using observed trends [3,21] and future climate scenarios [2], and to the role of extreme flood events [5,6], also by means of simplified [1] or empirical [6] prediction models.

Finally, the use of high-resolution Satellite Precipitation Products [14] and emission scenarios [15,16] as inputs for the hydrological model allowed us to improve the existing hydrologic forecasting system and detect the impacts of climate changes on the hydrological regime.

Acknowledgments: The Guest Editors thank all the authors, *Hydrology*'s editors and the reviewers for their contributions and commitment to this Special Issue. A special thank you goes to *Hydrology*'s Managing Editor, for her dedication to this project and her valuable collaboration in the design and setup of the Special Issue.

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

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