*Editorial*

# Advances in Environmental Hydraulics

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*Environmental Hydraulics* (EH) is the scientific study of environmental water flows and their related transport and transformation processes affecting the environmental quality of natural water systems, such as rivers, lakes, and aquifers, on our planet Earth [1]. In this broad sense, EH studies the motion of water at several different length and time scales, the fate and transport of species, dissolved and suspended, carried along by this fluid, and the interactions among those flows and the geological, biological, and engineered systems. EH problems can be tackled by using theoretical analyses, field studies, laboratory measurements on physical models, and numerical simulations. While classical Hydraulics deals with the design and operation of water supply and urban and rural drainage networks, EH is mostly aimed at the prediction and decision about water quality in natural channels. Hence, EH integrates the traditional analyses of classical Hydraulics in terms of discharge, velocity, water level and pressure with that carried out in terms of mass loading rate, flux, and concentration. Except for groundwater flows, EH flows are inevitably turbulent, due to the large scales that they typically occupy in natural water systems [1]. Turbulence is an extremely efficient agent of dilution; however, on the other hand, the complex motions that it generates are beyond any easy description, even by a statistical approach. Currently, a comprehensive theory of turbulence is still missing [1]. The other fundamental ingredient of EH is stratification, which is related to density differences, due to heat, salinity, or suspended matter [1]. In addition to turbulence, in EH, serious difficulties usually arise from the large size of the domain, two phase flows (e.g., water and sediment, water, and air bubbles) and a large variability in boundary conditions, forcing mechanisms, etc.

EH involves several substances, both reactive and non-reactive, such as natural inorganic salts and sediments, waste heat, organic wastes, trace metals, synthetic organic chemicals, and radionuclides. They can be naturally present or be produced by human activities and may be discharged into natural waters through *point sources*, such as municipal and industrial discharges, and *non-point* or *diffuse sources*, such as agricultural, silviculture, atmospheric, urban and suburban runoff, and groundwater infiltration.

EH processes can be categorised into two broad groups. *Transport processes* are those moving a substance from a point to another within the bulk water and across its surrounding boundaries, such as advection, molecular and turbulent diffusion, gas-transfer, sediment transport, hyporheic exchange, and wave induced drift. Those surrounding boundaries, termed *environmental interfaces*, are air–water [2], water–sediment [3], water–aquatic organisms [4], water–vegetation [5], and water–porous medium [6] interfaces. Hence, EH is a key point in the water–ecology nexus. *Transformation processes* are those changing a substance into another substance. We can have physical, chemical, and biological transformations.

EH goes back to approximately 10,000 years ago, when most people on Earth became sedentary farmers starting to live concentrated around wells, lakes, rivers, and other

sources of water in growing urban centres acting as sources of wastewater discharge [7]. The management of such discharges to minimise the risk of microbiological pollution with the associated impacts on human communities was the original focus of EH, which was unique or largely predominant until 20th century. This long period of time can be called the *Public Health Age* of EH. Since the 18th century, the risk of microbiological pollution was drastically reduced using drinking water filtering and later in the early 20th century, systematic chlorination [8]. With the growing industrialisation and urbanisation of the western world, the EH focus shifted to the concerns over the water quality of surface and groundwaters due to urban and industrial wastewater discharges. Hence, EH moved from the *Public Health Age* to the *Water Quality Age*, in which increasing efforts were devoted to the development of methods and tools for water quality modelling [9]. Since the new millennium, the scientific focus of EH has been oriented towards the integration of water quality-based approaches with (1) the large body of new knowledge about fluid turbulence; (2) the impressive advancements in river morphodynamics; and (3) the full consideration of the connections between physical, chemical and biotic components of a natural water system around the concept of *environmental interface* [1]. This originates the *Integrated Environmental Hydraulics Age*.

The overall goal of this Special Issue of Water was to present and discuss the recent advancements in the field of Environmental Hydraulics. For this Special Issue, papers reporting theoretical, field, laboratory, and numerical investigations on the above phenomena and processes, as well as on their ecological implications for natural water systems, were considered. This Special Issue collected two review articles and 10 original research articles with a broad range of scientific problems, physical processes, and natural water systems. One review paper [10] features the historical evolution of EH and the observed shift in its research trends through the bibliometric analysis of the latest EH literature. The second review paper [11] deals with the environmental impacts associated with the rapidly growing mariculture industry, while one research paper [12] investigated the flow and concentration patterns downstream an aquaculture cage net panel in parametric flume experiments. Four studies approached the stream and river systems from a variety of perspectives, ranging from the physical modelling of flow with vegetation [13] and the numerical simulation of solute transport in river with dead zones [14], to the laboratory study of flood discharge atomisation [15] and the geomorphic characterisation and classification of a large river [16]. Three contributions are about hyporheic fluxes: two field studies investigated these fluxes at a small river confluence [17] and the effects of such fluxes on the macroinvertebrate community [18], while their relationship with the bioturbation activity of macroinvertebrates was studied in laboratory [19]. The last two articles addressed the accuracy of groundwater flux measurement using a seepage meter in the laboratory [20] and the experimental validation of the Darcy–Buckingham (DB) law in unsaturated porous rocks [21]. The research articles apply theoretical, field, laboratory, and numerical methods to address their scientific questions, which are related both to classical EH themes and to broad and important morphological and ecological issues of natural water systems. Ultimately, this Special Issue aimed to provide the latest developments of the ever-growing and evolving field of EH.

Zeng et al. [10] reviewed how EH, as a subdiscipline, has evolved from its origin and traced the shift of its latest research trends in the last 20 years. The authors first provided an overview of the historical evolution of EH describing in detail the earlier mentioned ages, namely the Public Health Age, the Water Quality Age and the Integrated Environmental Hydraulics Age. The authors conducted a bibliometric analysis of the EH literature using the proceedings of the International Symposium on Environmental Hydraulics (ISEH) (2004–2018) and research articles from the *Environmental Fluid Mechanics* (*EFMC*) journal (2001–2020). Nationality and affiliation information were analysed using Citespace to identify patterns of collaboration among scientific institutions and authors. The major EH topics over the study period were identified through automated content analysis implemented in Leximancer, and then analysed from the expert perspective,

with their trend of change as well as the similarities and differences between the two datasets discussed.

Marine aquaculture, or mariculture, has been growing rapidly throughout the world in recent decades, but its associated environmental impacts have also attracted growing concerns. In this context, Wang et al. [11] provided a synthetic overview on these issues by reviewing and discussing the characterisation, transport, and current modelling and management tools associated with effluents released from mariculture sites. The authors examined the effluent characteristics and behaviour from source-to-sink, including the composition and load of effluent discharge, its transport and transformation processes in the water column and at the seabed, and its impacts on the pelagic and benthic environments. They also reviewed management-related issues, including the setting of the regulatory mixing zone, the establishment of environmental standards, monitoring measures, and modelling techniques to reveal the current state-of-the-art in a global context. In conclusion, the authors called on more international efforts to be orchestrated towards establishing the consistent regulatory framework worldwide as well as the proper evaluation and validation of predictive models given their increasing application in regulatory practices.

Cage-based aquaculture has been growing rapidly in recent years, and the clustering of large quantities of cages in fish farms located in inland lakes or reservoirs and coastal embayments or fjords significantly affects flow and mass transport in the surrounding waters. To address this issue, Shao et al. [12] employed the combined particle image velocimetry and planar laser induced fluorescence (PIV-PLIF) flow imaging technique to measure turbulence characteristics and associated mass transport in the near wake of a steady current through an aquaculture cage net panel in parametric flume experiments. In the near wake region, defined as ~3 M (mesh size) downstream of the net, the flow turbulence was observed to be highly inhomogeneous and anisotropic in nature. Overall, the presence of the net panel slightly enhanced the lateral spreading of the scalar plume, but the lateral distribution of the scalar concentration, concentration fluctuation and transverse turbulent scalar flux exhibited self-similarity from the near wake region where the flow is still strongly inhomogeneous.

Recently, vegetated flow has received tremendous attention as evidenced by the rapid growth of scientific publications dealing with this topic. While studies focused on the flow–plant interaction were mostly performed on smooth channel beds, natural riverbeds are characterised by other roughness elements that also affect flow turbulent structures. As such, Penna et al. [13] performed an experimental study on the bed roughness effects on the turbulence characteristics in an open-channel flow with rigid emergent vegetation. The results showed that the flow was strongly influenced by the vegetation in the intermediate layer below the free surface and was affected by a combined effect of vegetation and bed roughness in the near bed layer. The latter zone became more extended with the increasing bed sediment size. The shear stress distributions confirmed the existence of the two distinct flow regions. Turbulent kinetic energy (TKE) exhibited high values below the crest level and in the near-bed flow zone in the streamwise direction, whereas a strong lateral variation of TKE from the flume centerline to the cylinder occurred in the intermediate region.

The one-dimensional (1D) advection–dispersion equation (ADE) is widely adopted to analytically model solute transport in streams due to its simplicity, versatility, and computational efficiency. However, natural streams often contain complexities such as transient storage zones (dead zones), vegetation and irregular stream morphology that could interfere with the solute transport processes, causing a strong asymmetry in the shape of the concentration distribution curve over time and invalidating the Gaussian distribution traditionally assumed in classic 1D ADE. To address this issue, Sokáč et al. [14] proposed a simple 1D model with alternative asymmetrical statistical distributions, such as Gumbel, log-normal and generalised extreme value (GEV), for solute transport in streams with dead zones. Tests against literature field tracer experiments as well as data collected in three small streams in Slovakia with dead zones suggested that, compared with Gaussian distribution, the alternative formulations overall showed a significantly

improved prediction of the dispersion process from an instantaneous source. The authors further demonstrated the applicability of the new formulation in solving inverse tasks.

Atomised flow during flood discharge in large hydraulic infrastructures can induce super-heavy rain and widespread mist causing severe flooding and landslides as extreme natural rainfall events. A better understanding of the atomised rain characteristics in low ambient pressure environment is critical for mitigating the jeopardising effect of flood discharge atomisation for high-altitude hydropower stations. To this end, Liu et al. [15] designed a random splash experiment in a depressurised chamber to evaluate the effects of low ambient pressure on downstream atomised rain created by a high-velocity waterjet. The results demonstrated that the downstream distribution of the atomised rain, the point rain intensity and surface rain amount increased with decreasing ambient pressure and increasing inflow discharge, which can be attributed to the aeration reduction in the waterjet boundary and the resistance reduction in atomised water droplets.

Nardini et al. [16] addressed the geomorphic characterisation and classification of large rivers in a framework of scarce information. Inspired by the River Styles Framework, the authors made some modifications to the original characterisation and classification procedure to make it more straightforward and accessible to practitioners and more applicable to large basins framework by using computer-aided tools that minimised expert-based inputs and increased systematisation and objectivity. The authors further showcased the application of the methodology to a large river, the Magdalena River, Colombia, and highlighted the great geomorphic diversity of the river.

Confluences are nodes in riverine networks characterised by complex three-dimensional changes in flow hydrodynamics and riverbed morphology and have important ecological functions. While much has been studied on its water column or riverbed, few studies have focused on hyporheic fluxes of this complex system. To address this gap, Martone et al. [17] conducted a field study to characterise the spatial and temporal patterns of hyporheic flux subject to confluence physical drivers at a low gradient, headwater confluence in Marcellus, NY, USA. Confluence geometry, hydrodynamics, and morphodynamics were found to significantly affect hyporheic exchange rate and patterns. Seasonal or event-driven variations in hydrological conditions were also observed to play a role on hyporheic fluxes.

Hyporheic exchange affects the substrate properties and water quality and thus the habitat availability and suitability of macroinvertebrate community in river ecosystems. In this context, Lin et al. [18] conducted a field study to explore the impacts of magnitude and pattern (upwelling and downwelling) of hyporheic exchange on the sediment macroinvertebrate community in the Weihe River Basin in Shaanxi, China. The results showed that while upwelling flows caused the resuspension of riverbed sediment and increased the proportion of swimmer groups in the macroinvertebrate community, downwelling is more likely to produce abundant and rich invertebrate communities. The authors also identified an optimal hyporheic flux of 150–200 mm/d for preserving community abundance and diversity in their study area.

At the same time, the bioturbation activity of macroinvertebrates can affect the water exchange across the sediment–water interface (SWI) in the hyporheic zone. Mao et al. [19] studied the impact of tubificid worms as a dominant group of benthic macroinvertebrates on the vertical water exchange across the sediment–water interface through laboratory flume experiments. The results showed that tubificid bioturbation affected the vertical water flux and penetration depth across the SWI, and such effects had pronounced correlation with both density and duration of bioturbation. Specifically, the vertical water flux was initially positively correlated with the tubificid bioturbation when the tubificid density is low (less than or equal to 20 ind/10 cm$^2$) and shifted to negative correlation when the tubificid density exceeded certain threshold (greater than or equal to 25 ind/10 cm$^2$) or the bioturbation lasted for extended period (after 14 to 21 days). In addition, the maximum penetration depth increased with increasing tubificid density.

It is thus essential to understand the water exchange between groundwater and surface water for effective water resources and river management, and an important method to

quantify the water exchange is to use a seepage meter, which directly measures the influx and outflux of groundwater. Lee et al. [20] performed a systematic evaluation on the accuracy of groundwater flux measurement using a seepage meter through a series of laboratory experiments under controlled flow conditions. Comparison against known water flux rates in the controlled tank flow system confirmed that the flux rate directly measured using a seepage meter may not represent the actual flux rate. Measured influx rates tended to be lower than the actual value and outflux rates higher than the actual value. The authors also compared the differences that arose from the use of different types of collection bags and analysed the potential source of the measurement errors.

The Darcy–Buckingham (DB) law, i.e., direct proportionality between the flux through a porous medium and the net force that drives it, is widely applied in subsurface hydrology but has rarely been experimentally tested, particularly under unsaturated conditions. Complementary to the few previous tests performed on soils, Turturro et al. [21] tested the DB law on two lithotypes of unsaturated calcareous porous rocks. The quasi-steady centrifuge method was used to measure the flux density for different centrifugal driving forces while maintaining essentially constant water content. The results confirmed the validity of the DB law for the tested rocks and conditions, including consolidated media, bimodal pore-size distribution, and the possible deformation of the air–water interface.

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