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Editorial

Twenty-Five Years of Hydroinformatics

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Abstract: Hydroinformatics emerged in 1991 when numerical modelling of water expanded its range from one that was restricted to the modelling of flows to a much wider ranging sociotechnical discipline that supports stakeholders in addressing their water-related problems. However, despite numerous advances in hydroinformatics, the current practical and research effort is still very much technocratic (or techno-centric) which in turn may restrict the potential of hydroinformatics in its scope and its reach. This Special Issue, through the compilation of thirteen papers, illustrates some of the developments and applications in the field of hydroinformatics and marks the twenty-five years of its existence. We hope that this will help to further raise the awareness of the subject and its developments and applications. In the Editorial of this Special Issue, we briefly discuss the origin of hydroinformatics and we introduce the papers that are featuring in this Special Issue. We also give a way forward for future research and application.

Keywords: hydroinformatics; numerical modelling; computational hydraulics; data collection and processing; sociotechnology; stakeholders; holistic planning

1. Introduction

Water related problems are ranked as some of the greatest problems facing mankind in the present century. It has become evident that the world's availability of water is reduced due to excessive consumption, contamination of aquifers, inadequate waste management, lack of proper water collection and distribution technologies, and excessive farming. There are numerous reports that over 1 billion people in developing countries lack access to safe drinking water and almost 3 billion have no access to adequate sanitation facilities.

Climate change has also become a challenging factor: changes in rainfall patterns are making traditional water systems less and less effective (e.g., drainage and flood protection, water control, storage and distribution facilities and so on), [1–6].

Despite the fact that our technological capabilities for dealing with hydro-meteorological events have advanced rapidly over the last hundred years and while global economic growth per capita has doubled, such events have become ever more disastrous (see for example, [7]). This situation was already questioned in [7,8] and to a certain extent also in [9–11]. Hydroinformatics offers a considerable opportunity to address some of these water-related issues in a way that it can meaningfully provide integration between data, models and decision support.

Since its birth in 1991 [10], and with its roots coming from computational hydraulics [12], hydroinformatics has evolved into a well-established field of study supported with its scientific Journal, biannual conferences and undergraduate and postgraduate courses which are being taught around the world. With the extension of hydroinformatics onto the sociotechnical dimension, as projected already in [10], the role of hydroinformatics has become broader and even more important within the wider water management area. Hence, a more recent formulation of the purpose of hydroinformatics is given in [11]:

> *the purpose of hydroinformatics is to transform the corresponding social environment from a reactive one, (in which each stakeholder reacts individually during the course of a purely technical transformation and solely on the basis of the most immediate social consequences for that individual stakeholder) into an interactive one (in which each stakeholder interacts with the other stakeholders within a community, whereby the different stakeholders come to cooperate in the forming and shaping of the transformation as a whole, making of it an essentially sociotechnical transmutation).*

Therefore, the primary role of hydroinformatics nowadays is in the development and installation of sociotechnical arrangements that can truly enable the right balance between *quantities* (i.e., *measurable substance, matter, structure*) and *qualities* (i.e., *patterns, dependences, interrelationships, contexts, perceptions, feelings, emotions, subjective experiences*, etc.) and apply them meaningfully in our research and practice, see also [11,13–20], Figure 1. Along with this, the traditional perception of hydroinformatics has to change into one where ideas emerge from *qualities and social needs and concerns* and proceeds through indefinable feedback cycles where the acceptable social, ethical, technical and environmental norms and standards continuously change, leading to a better understanding of phenomena and better interventions into the physical environment. This view, necessitates, and therefore *transcends*, the traditional way of thinking and working within hydroinformatics by incorporating the qualitative way of working (see also, [11]), Figure 2. It is important to emphasise that our discussion here does not imply that we want to disregard modern science. On the contrary, the purpose of *qualities* and *qualitative way of working* is rather complementary and it is to gain a more comprehensive and complete encounter with the phenomena and issues at stake.

This Special Issue marks the twenty-five years of hydroinformatics through compilation of fourteen papers that span across different topics, from updating Intensity–Duration–Frequency (IDF) curves to gain better understanding of climate change effects, numerical modelling using different model formulations, evaluation of systems and measures (green/suds, grey, etc.), evolutionary system optimisation to decision support through new generation of GIS maps, evidence-based intelligence and serious gaming.

In the following section, we discuss the origin and purpose of hydroinformatics. Although we cite some of the earlier work published, it is beyond the scope of this Editorial to provide a comprehensive review of all possible *hydroinformatics* publications that appeared over the last twenty-five years and therefore we had to be limited in this regard. Hence, more interested readers are encouraged to source other relevant publications.

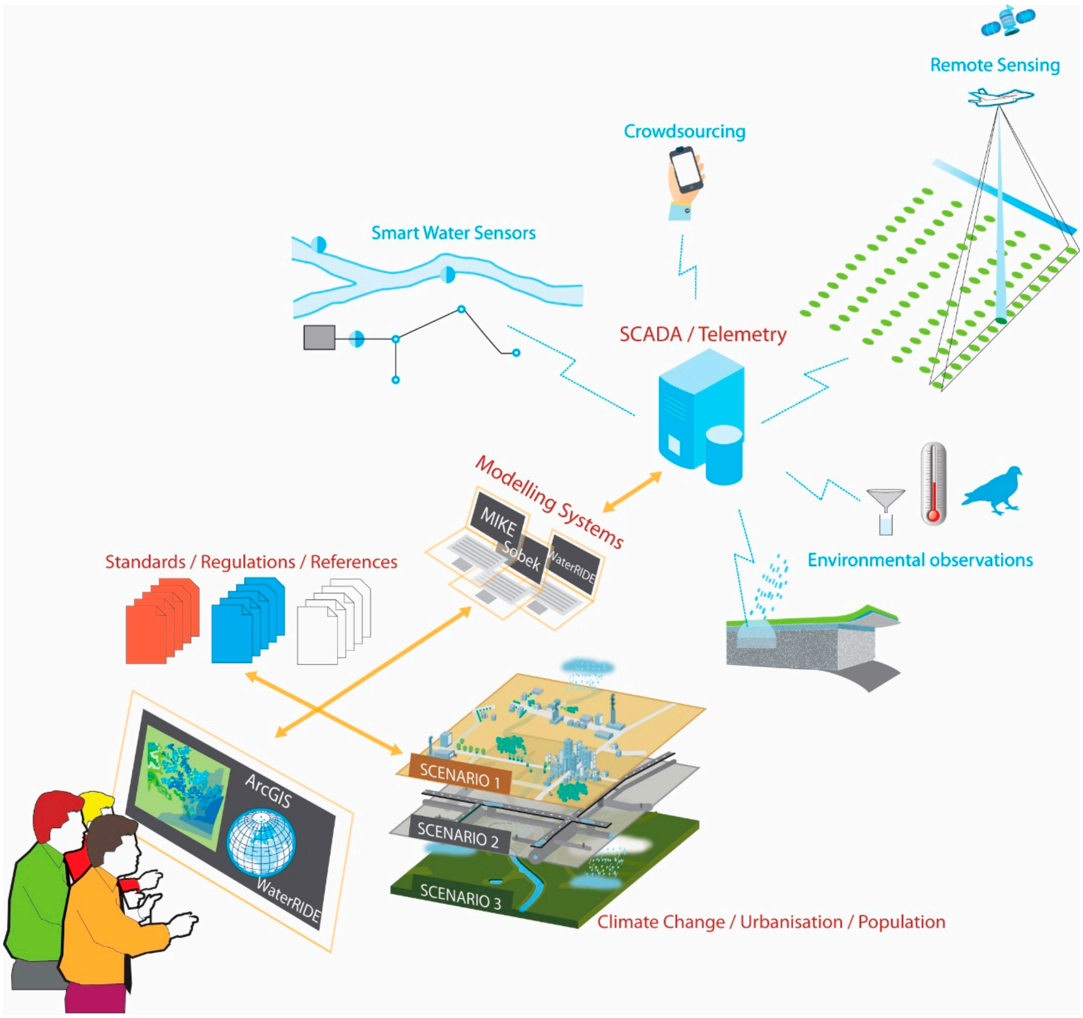

Figure 1. Illustration of *hydroinformatics environments* which have the primary aim of enabling stakeholders to *co-develop* their water-related solutions in a *holistic* way.

Figure 2. Flood hazard and risk perception group mapping exercise with community representatives in Ayutthaya, Thailand. Community groups were asked to produce maps and drawings with their personal experiences from flood events, i.e., *a qualitative way of working* (see also [21]).

2. On the Origin and Purpose of Hydroinformatics

Unfortunately, at the time of preparing for this Special Issue, there is still a prevailing thought that hydroinformatics is exclusively concerned with mathematical modelling and decision support. Although the discipline first emerged when Abbott [10] identified a synergetic relation between numerical modelling [17], data collection, and processing, at the end of the 1980s, *it now has much broader objectives* (see also, [14]).

Since its inception, hydroinformatics has incorporated the social dimension of water infrastructure [18,19] by attending to those social and technical processes that cannot be separated from each other. The above definition and purpose of hydroinformatics can be also expressed as [11]:

> *hydroinformatics integrates knowledges from the social and technical domains to create so-called conjunctive knowledges, that are concerned with an understanding of how technical interventions have social consequences and how the resulting social changes in turn generate new technical developments.*

The sociotechnical view (which incorporates both social and technical domains) has now become an essential aspect of hydroinformatics. The sociotechnical nature of water problems arises from the complexity of interrelated phenomena and the large number of stakeholders and their diverse needs. Therefore, the role of the hydroinformatician in this process is to [11]:

> *create socio-technical environments in which the transmutations necessary to provide states of social justice can be catalysed through the creation of appropriate socio-technologies.*

The new paradigm in hydroinformatics necessitates a new way of working, which is indeed holistic, and which can be defined as a transcendental praxis [18–20,22]. The holistic way of working in hydroinformatics is based on the notion that the properties of a complex system (such as water and its environment) can be understood only within the context of the larger whole. Such a way of thinking and working emerged through different disciplines and movements. These are primarily from phenomenology (i.e., the works of Brentano, Meinong, Husserl, Heidegger, Scheler, Merleau-Ponty, Sartre and others), Gestalt psychology (i.e., the works of Ehrenfels, Koffka, Wertheimer and Köhler), organismic biology (i.e., the works of Harrison, Henderson, Woodger and others), the romantic movement in art, literature and philosophy (i.e., the works of Goethe, Blake, Kant), ecology (i.e., the works of Haeckel, von Uexküll, Lovelock, Patten and others), general system theory (i.e., the works of von Bertalanffy), cybernetics (i.e., the works of Wiener, Forrester), quantum physics (i.e., the works of Planck, Heisenberg, Bohm and others) and so on (see also, [8] and [11]).

It is important to note that the holistic way of thinking and working combines qualities and quantities for the purpose of gaining a better understanding of the phenomena under consideration. Bortoft [20] calls this a counterfeit whole reduced to the sum of its parts, in contrast to the authentic whole in our mind's eye where each part is an intuitive expression of the whole.

We note that although the current resources and efforts in hydroinformatics are largely based upon a modern scientific (which are here regarded as *quantitative*) way of thinking and working, the focus now, and increasingly, has to be shifted towards a *hydroinformatics of the qualities*. This is to say that for an in-depth understanding of those aspects that cannot be easily (or not at all) expressed in numerical and/or monetary terms and which are based on cultural values, opinions, judgements, feelings, and perceptions, a holistic approach which combines a range of quantitative and qualitative data and methods should be adopted (see for example [21]).

The following section discusses some future prospects for hydroinformatics.

3. The Future of Hydroinformatics

The future of hydroinformatics is directed at supporting and indeed enabling *holistic* analysis, design, installation and development of on-line and real-time construction, operation and management of water systems that will be highly adaptive to changing conditions, such as those that may occur slowly over years (e.g., climate change effects) and over a few hours (e.g., flood conditions), or in extreme cases even over some minutes (e.g., evacuation of people in advance of disastrous events). In most cases, such developments will remain under constant refinement in order to accommodate changes that will occur in different application areas. They will thus be highly dynamic and strongly self-referencing.

The efforts concerning the development and use of numerical modelling systems will be increasingly directed towards coupling of different kinds of models and instantiation of models via web-based applications as well as better data processing activities (including quantification of uncertainties) that can enable more accurate model results. Such developments will greatly influence the accuracy with which modelling can respond to the increasing challenges with which it is confronted (see for example, [3,11,23–32]).

Gathering and processing terrain and bathymetry data with new technologies and tools (including real-time data transmission and operation through Real Time Control, RTC, and Supervisory Control And Data Acquisition, SCADA, systems) is yet another important activity in hydroinformatics and as such it is also likely to remain in the focus for future research (see for example [28–30,33,34]).

The above-mentioned developments will be invaluable adjuncts to the *holistic* planning and the implementing of investments, system optimisation and rehabilitation projects, see for example [8,21,23–27,33,35–48]. For example, the move away from 'hard' structural protection (also referred to as 'grey' measures), as afforded by dykes or pipes, and more towards green infrastructure (also referred to as 'nature-based' solutions) will make it possible to achieve multiple benefits of urban infrastructure and better utilisation of urban space. Similarly, and by way of another example, the ongoing and intensified introduction of on-line water-quality measuring and monitoring systems with their SCADA systems providing effective on-line communications to decision enhancing facilities of all kinds (including the means for crowdsourcing and the use of mobile phone applications), as directed in turn to all manner of 'decision-makers' including the general population, will provide greatly enhanced warning facilities and associated customised advice. Thus, finding the right combination of green and grey infrastructure supplemented with on-line and real-time installations will provide the essential prerequisites for the future socio-economic developments in the urban water sector.

It follows also that our efforts in hydroinformatics will not only be directed at providing the means to implement design, implementation and management procedures directed towards one complete and final situation, but also they will be directed towards the installation of systems that will monitor the changing, interacting, social and technical environments occurring, while considering the changing socio-economic and more general social conditions in order to evolve with new strategies that are more flexible and able to adapt to the changing situation while still leading development in direction set by the stakeholders. The approach that is envisioned here is then incremental, sequential, reflexive and evolutionary rather than being first discontinuous and afterwards static. This approach is currently being applied in hydroinformatics itself through complex adaptive systems theory (complexity theory), multi-agent system theory (agent-based models), evolving automata (cellular automata, see for example [43,44]), game theory, nonlinear dynamics theory, chaos theory and fractal geometry, computational sociology, autopoietic network theory, and so on (more interested readers can also refer to the EC funded PEARL project, www.pearl-fp7.eu). A system of this kind is commonly described as an essentially sociotechnical system that can enable addressing both *qualities* and *quantities*.

The following section gives an overview of the papers featuring in this Special Issue.

4. This Special Issue

The following papers are featuring in this Special Issue:

- The paper of Doong et al. [49] deals with the development of a new generation of flood inundation maps for the Coastal City of Tainan (Taiwan). The paper describes efforts in developing the new generation of flood inundation maps at the city scale and to demonstrate the effectiveness of such maps in the case of the coastal city of Tainan, Taiwan. Besides pluvial floods, the storm surge influence is also considered. The 1D/2D coupled model SOBEK was used for flood simulations. Different indicators such as Probability of Detection (POD) and Scale of Accuracy (SA) were applied in the calibration and validation stages of the work and their corresponding values were found to be greater than 60%. The work undertaken suggests that land elevation, tidal phase, and storm surge are the three dominant factors that influence flooding in Tainan. A large number of model simulations were carried out in order to produce FIMs which were then effectively applied in the stakeholder engagement process.

- The paper of Jato-Espino et al. [50] describes the work on coupling GIS with stormwater modelling for the location prioritization and hydrological simulation of permeable pavements in urban catchments. Their work addresses the design of a site selection methodology for the location prioritization of permeable pavement systems (PPS) in urban catchments, in order to simulate their potential to attenuate flooding caused by severe rainfall events. This was achieved through the coupling of Geographic Information Systems (GIS) and stormwater models, whose combination provided a framework for both locating and characterizing PPS. The usefulness of the methodology was tested through a real case study consisting of an urban catchment located in Espoo (southern Finland), which demonstrated that PPS can make a significant difference in the amount of runoff generated in an urban catchment due to intense storms.
- Savic et al. [51] present their efforts in developing serious gaming tools for water systems planning and management. Their paper focuses on Serious Games (those used for purposes other than mere entertainment), with applications in the area of water systems planning and management. A survey of published work on gaming is carried out with particular attention given to applications of Serious Gaming to water systems planning and management. The survey is also used to identify the principal criteria for the classification of Serious Gaming for water related applications, including application areas, goals, number and type of players, user interface, type of simulation model used, realism of the game, performance feedback, progress monitoring and game portability. The review shows that game applications in the water sector can be a valuable tool for making various stakeholders aware of the socio-techno-economic issues related to managing complex water systems. However, the critical review also indicates a gap that exists in the Serious Game application area with the lack of water distribution system games. A conceptually simple, but computationally elaborate new game for water distribution system analysis, design and evaluation (SeGWADE) is presented in this paper. It has a main goal of finding a least-cost design for a well-known benchmark problem, for which the game environment takes the computational and visualisation burden away from the simulation tool and the player. The game has been evaluated in a classroom environment in which a high degree of player engagement with the game was observed, due to its basic game ingredients and activities, i.e., challenge, play and fun. In addition, a clear improvement in learning has been observed in how players attempted to identify solutions that satisfy the pressure criterion with players readily identifying the proximity of the better solutions to the starting, infeasible configuration. Through applications of Serious Gaming such as this, decision makers can learn about the complexity of the water distribution system design problem, experiment safely using a computer model of a real system, understand conflicting objectives (i.e., minimization of cost and satisfaction of minimum pressure) and develop strategies for coping with complexity without being burdened by the limitations of the ICT technology at their disposal.
- Alves et al. [52] deal with the evolutionary and holistic assessment of green–grey infrastructure for CSO reduction. This work presents a novel methodology to select, evaluate, and place different green–grey practices (or measures) for retrofitting urban drainage systems. The methodology uses a hydrodynamic model and multi-objective optimization to design solutions at a watershed level. The method proposed in this study was applied in a highly urbanized watershed to evaluate the effect of these measures on Combined Sewer Overflows (CSO) quantity. This approach produced promising results and may become a useful tool for planning and decision making of drainage systems.

- Karavokiros et al. [53] present Evidence-Based, Intelligent Support for Flood Resilient Planning and Policy which is part of the FP7 EC funded PEARL project. The intelligent knowledge-base (PEARL KB) of resilience strategies is presented here as an environment that allows end-users to navigate from their observed problem to a selection of possible options and interventions worth considering within an intuitive visual web interface assisting advanced interactivity. Incorporation of real case studies within the PEARL KB enables the extraction of (evidence-based) lessons from all over the word, while the KB's collection of methods and tools directly supports the optimal selection of suitable interventions. The Knowledge-Base also gives access to the PEARL KB Flood Resilience Index (FRI) tool, which is an online tool for resilience assessment at a city level available to authorities and citizens. The authors argue that the PEARL KB equips authorities with tangible and operational tools that can improve strategic and operational flood risk management by assessing and eventually increasing resilience, while building towards the strengthening of risk governance. The online tools to which the PEARL KB gives access, demonstrate the case of Rethymno, Greece.
- Pedersen et al. [54] present their work on updating conceptual rainfall-runoff models using Maximum a Posteriori estimation to determine the most likely parameter constellation at the current point in time. This is done by combining information from prior parameter distributions and the model goodness of fit over a predefined period of time that precedes the forecast. The method is illustrated for an urban catchment, where flow forecasts of 0–4 h are generated by applying a lumped linear reservoir model with three cascading reservoirs. Radar rainfall observations are used as input to the model. The effects of different prior standard deviations and lengths of the auto-calibration period on the resulting flow forecast performance are evaluated. The authors were able to demonstrate that, if properly tuned, the method leads to a significant increase in forecasting performance compared to a model without continuous auto-calibration. Delayed responses and erratic behaviour in the parameter variations are, however, observed and the choice of prior distributions and length of the auto-calibration period is not straightforward.
- Irwin et al. [55] present ResilSIM, a decision support tool for estimating the resilience of urban systems. The ResilSIM is a web-based tool (with mobile access) that operates in near real-time. It is designed to assist decision makers in selecting the best options for integrating adaptive capacity into their communities to protect against the negative impacts of a hazard. ResilSIM is developed for application in Toronto and London, Ontario, Canada; however, it is only demonstrated for use in the city of London, which is susceptible to riverine flooding. It is observed how the incorporation of different combinations of adaptation options maintain or strengthen London's basic structures and functions in the event of a flood.
- The paper of De Corte and Sörensen [56] deals with an iterated local search algorithm for multi-period water distribution network design optimization. In this paper, the well-studied single-period problem is extended to a multi-period setting in which time varying demand patterns occur. Moreover, an additional constraint—which sets a maximum water velocity—is imposed. A metaheuristic technique called iterated local search is applied to tackle this challenging optimization problem. A full-factorial experiment is conducted to validate the added value of the algorithm components and to configure optimal parameter settings. The algorithm is tested on a broad range of 150 different (freely available) test networks.
- The work of Thuy Ngo et al. [57] deals with the optimization of upstream detention reservoir facilities for downstream flood mitigation in urban areas. Their work couples hydrologic simulation software (EPA-SWMM) with an evolutional optimizer (extraordinary particle swarm optimization, EPSO) to minimize flood damage downstream while considering the inundation risk at the detention reservoir. The optimum design and operation are applied to an urban case study in Seoul, Korea, for historical severe flooding events and designed rainfall scenarios. The optimal facilities outperform the present facilities in terms of flood damage reduction both downstream and in the detention reservoir area. Specifically, the peak water level at the detention pond under

optimal conditions is significantly smaller than that of the current conditions. The comparison of the total flooded volume in the whole watershed shows a dramatic reduction of 79% in a severe flooding event in 2010 and around 20% in 2011 and in 180 min designed rainfall scenarios.

- The paper of Campbell et al. [58] deals with a novel water supply network sectorization methodology based on a complete economic analysis, including uncertainties. They implement a development proposed by the International Water Association (IWA) to estimate the aforementioned benefits. Such a development is integrated in a novel sectorization methodology based on a social network community detection algorithm, combined with a genetic algorithm optimization method and Monte Carlo simulation. The methodology is implemented over a fraction of the water supply networks of Managua city, capital of Nicaragua, generating a net benefit of 25,572 $/year.
- The work of Yong Choi et al. [59] analyses the effect of sampling interval when an adaptive Kalman filter is used for detecting bursts in a water distribution system. A new sampling algorithm is presented that adjusts the sampling interval depending on the normalized residuals of flow after filtering. The proposed algorithm is applied to a virtual sinusoidal flow curve and real district meter area (DMA) flow data obtained from Jeongeup city in South Korea. The simulation results prove that the self-adjusting algorithm for determining the sampling interval is efficient and maintains reasonable accuracy in burst detection. The proposed sampling method has a significant potential for water utilities to build and operate real-time DMA monitoring systems combined with smart customer metering systems.
- The work of Abebe et al. [60] deals with the investigation of effects of partial and full elimination of convective acceleration terms (CATs) within three 1D models and two 2D models. The models' performances were evaluated on hypothetical case studies which represent some characteristics of urban floodplains. Simulations results were compared against the solutions of the method that solves the full equations as a reference. Findings of the numerical tests show that, in most cases, results of models which ignore CATs fully were very similar compared to solutions of the model which implement full SWEs. Hence, the work presented indicates that the simplified models which ignore CATs may be used to model urban flood plains without significant loss of accuracy.
- The work of Hellmers and Fröhle [61] deals with modelling the so-called green infrastructure or sustainable drainage systems (SUDS). In this paper, a theoretical approach to integrate a detailed water balance calculation of SUDS with cascading effects in a meso-scale catchment model is presented. This approach has been implemented in a semi-distributed rainfall-runoff model and first physical model tests were used to verify the model results. The results from the case study of Hamburg (Germany) were used to demonstrate the efficiency of the small-scale measures to mitigate the flood peak discharge in an urban catchment area.
- The work of Shrestha et al. [62] addresses the issue of updating Intensity–Duration–Frequency (IDF) curves to gain a better understanding of climate change effects. The paper explores an approach based on spatial downscaling—temporal disaggregation method (DDM) to develop stochastic future IDFs using a stochastic weather generator, Long Ashton Research Station Weather Generator (LARS-WG) and the stochastic rainfall disaggregation tool, Hyetos. The work was carried out for the case of Bangkok, Thailand. The application of LARS-WG to project extreme rainfalls showed promising results and 15 Global Circulation Models (GCMs) were used to predict changes in IDF characteristics for future time periods of 2011–2030 and 2046–2065 under climate change scenarios. The IDFs derived from this approach were graphically corrected to mitigate biases. IDFs from all GCMs showed increasing intensities in the future for all return periods.

5. In Closing

Although this Special Issue has only touched upon some of the important aspects of hydroinformatics, we do hope that the papers that are featuring here will do much to raise awareness of the discipline and to enhance further developments (e.g., the EC funded PEARL project, www.pearl-fp7.eu and [63]). We are aware that we have only compiled few papers that can represent a small part of the subject—there is so much more that could be included in a series of Special Issues. We trust that this Special Issue, which marks twenty-five years of hydroinformatics, will help to raise the awareness of the subject and its developments and applications.

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