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Editorial

Arjen Y. Hoekstra: A Water Management Researcher to Be Remembered

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1. Introduction

On 18 November 2019, the life of Arjen Y. Hoekstra—an engaged researcher of global dimensions of water management, professor in multidisciplinary water management, founder of the Water Footprint Network and former editor-in-chief of the journal *Water*—came to a sudden and unexpected end.

In parallel both we, as research staff of the Arjen research group at the University of Twente, and the management of the journal *Water*, felt an urgency to devote a special issue to commemorate Arjen. The appearance of the special issue on 18 November 2020 was felt to be appropriate, and so was the choice to have the special issue consist of invited contributions of close (former) colleagues of Arjen, with whom he collaborated intensively, with whom he published joint papers that he valued highly, or both. We invited these colleagues to write on selected topics of Arjen's interest, trying to cover the wide range of his research interests.

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2. Materials and Methods

In his academic life, Arjen became most well-known for the creation of the water footprint concept, the active promotion of water footprint views in open discussion fora, and for initiating research collaboration, dissemination, and stakeholder engagement through the Water Footprint Network. In his work, however, the water footprint theme was not a goal in itself, but rather a point of condensation of his considerations on water management from different perspectives and at different scales.

The research interests of Arjen had a consistent direction throughout his career, starting as a Ph.D. student in 1993 at Delft University of Technology and working at the National Institute of Public Health and the Environment (RIVM, Bilthoven, the Netherlands), as senior researcher at the UNESCO-IHE Institute for Water Education, Delft, as full professor at the University of Twente and as visiting professor at the Lee Kuan Yew School of Public Policy, National University of Singapore.

In his Ph.D. thesis, *Perspectives on Water: An Integrated Model-based Exploration of the Future* [1], Arjen studied how cultural perspectives may drive countries or regions to adopt fundamentally different strategies to deal with water-related problems, how these perspectives translate in very different indicators of what good water management is, and how plausible future global development pathways may diverge under altering adherence of perspectives. Two of the propositions, addenda to the thesis, characterize Arjen's views:

- *In the future, problems of increasing water scarcity will, to less and lesser extents, be solvable by 'water policies' from 'water ministries', as the cause of water scarcity problems do not lie in water aspects, but in population and production growth;*
- *Making compromises in politics and governance is an essential condition for societal progress. Making compromises in science hampers academic progress.*

The first proposition emphasizes the relevance of alternative approaches to water management compared to traditional technocratic approaches of the cost optimization of the water supply to efficiently control water scarcity, and similarly, in other water management themes. The second proposition ventilates Arjen's strong belief that insights grow by sharply understanding what the essential differences in approaches and theories of scholars are, and not by remaining on common ground and focusing on improving methods and models. This belief may have made him appear provocative at times to some but also made him all the more appreciated by others for firing the substantive debate.

At UNSECO-IHE, Arjen developed the value-flow concept [2], considering the relation between the distribution of water use in a river basin and value creation (or loss) in processes that require water. This concept traces physical water flows in a basin (upstream-downstream), accounting for the (partly) consumptive and non-consumptive uses in the water balance and allows for interpretations in terms of economic efficiency and equity of water use in the basin. Next to these socioeconomic considerations on regional physical water use, at UNESCO-IHE he started focusing on the relevance of virtual water embedded in the international crop trade and the externalization of pressures on water resources [3]. He progressed to account for virtual water embedded in the trade of crop products in the water footprints of nations [4]. This was the foundation of the water footprint concept, taking a consumption-based perspective on water use that contrasts the traditional water management approach focusing on water use within a river basin, adding a relevant and previously missing indicator to the assessment of water management.

At the University of Twente, Arjen Hoekstra gave his inaugural address [5] under the title *Generalization as specialization. Water management in the context of sustainable development, globalization, uncertainties and risk*. In that address, he highlighted the relevance of economic policies and spatial planning for water management and emphasized the need to consider the globalization of water in water scarcity discussions (further specified in [6]). He stressed that important criteria to consider in societal progress and in water management are not only efficiency, but also justice (fairness/equity), sustainability and safety (robustness/resilience). Extreme conditions pose dominant challenges to water management. Where uncertainties in assessing such conditions are inherently high, he emphasized that a focus on the study of fundamental choices on directions of development is most relevant (further specified in [7]). In a closing statement, he mentioned that his work will be probably at least as recognizable for researchers in environmental sciences, systems ecology and macro-economy as for water engineers; this closely connects to his view of water management extending well beyond the classical domain of civil engineering.

His research in Twente initially pivoted around the sound establishment of the foundations of water footprint research by formalizing methods of water footprint accounting and water footprint assessment in many journal papers and in books [8,9], the latter of which (*The Water Footprint Assessment Manual: Setting the Global Standar*') has been translated in many languages. The focus of water footprint research extended from quantitative water analyses of crop production, the largest water-consuming sector globally by far, to more comprehensive studies.

One direction of extension was the coverage of water footprint accounting to also include animal products, heavily relying on crop product inputs [10,11]. The reliance of energy supply on water resources was studied in papers on footprints of bioenergy and electricity [12,13]. Additionally, the footprint estimation of commercial, industrial and institutional activities was refined and represented spatially [14].

Another direction of extensions concerned the range of environmental and societal aspects reflected in the footprint indicators. The grey water footprint, reflecting pressures on freshwater resources due to water pollution, was refined [15]. Water footprints were increasingly put in the context of a wider suite of environmental footprints [16]. Environmental footprint families which entered scenario studies on the sustainability of development [17] and of dietary patterns in human consumption highlighted the role of animal products in the diet [18]. Arjen highly valued critical discussion on the definition and interpretation of indicators, emphasizing that water footprints reflect environmental pressures and human appropriations of water resources, but do not directly reflect environmental impacts [19], highlighting differences in insight with how the LCA community adopted water footprints in a sharp open academic debate [20,21]. His approach to impacts following a water footprint sustainability assessment [9] were detailed to explicitly and spatially quantify the population experiencing water scarcity [22].

With the two directions of extension combined, Arjen valuably contributed to discussions on SDGs and on the water-food-energy nexus [23–25].

To disseminate his insights, Arjen actively and inspiringly engaged his university classes, his journal publications, books, and press appearances, as well as founded the Water Footprint Network, an NGO that aims to further water footprint research and to use the water footprint concept to promote the transition toward sustainable, fair, and efficient use of freshwater resources worldwide. In his latest book *The water footprint of modern consumer society* [26], he highlighted main drivers of water consumption (chapter *The meat eater, a big water user*), the relevance of supply-chain thinking (chapter *The supply-chain water footprint of paper*). The final chapter (*Who will be the heroes of change?*) stresses the joint responsibility of producers, consumers, and governmental institutions to establish changes reverting the current overuse of natural resources.

Arjen was fascinated by fundamental academic dilemmas and principal cultural differences. He highlighted them in many of his numerous publications, with some key publications referenced above, and in the prestigious ERC Advanced Grant he was awarded in 2019. Research initiated by him continues, and his legacy will remain to influence research on sustainable water management.

3. Discussion of Contributions to the Special Issue

This special issue consists of invited contributions of close colleagues of Arjen Hoekstra, whom we asked to reflect on specific water management issues they are familiar with, and on the contributions Arjen and his collaborators have had in that context. The water management issues were chosen to represent the envelope of Arjen's core work, ranging from conceptual developments, global applications of the water footprint concept to different sectors, production and consumption perspectives, the water-food-energy nexus, sustainability assessment, and regional applications of water footprint research.

3.1. Water Value Flows Upstream

The contribution by Savenije and van der Zaag [27] revives pioneering work from Hoekstra's early career [2]: the water value-flow concept. All benefits obtained from using water within a river catchment are derived from precipitation that feeds the system, and these benefits represent a value of the water. In a case study of the Zambezi River basin, Hoekstra and collaborators [2] postulated that while water flows in the downstream direction, the value of water accumulates in the upstream direction: water value flows upstream. Savenije and van der Zaag initiate their article with the observation that the innovative water value-flow concept has been largely ignored by scholars and practitioners in the fields of water management and economics. The authors aim to restore this lack of attention for the concept. To this end, they briefly review the water value-flow concept, suggest expanding it, consider its potential contribution to emerging scientific fields, explore its possible contributions to contemporary water challenges, and finally, formulate directions for future research to improve and apply the concept. Savenije and van der Zaag conclude that the water value-flow concept, through its integrated nature, could play a fundamental role in the fields of socio-hydrology and water accounting. Furthermore, the concept can make significant contributions to contemporary water challenges by (a) its consistency with the "Five Bellagio Principles on Valuing Water" published by the High Level Panel on Water; (b) effectuating the appreciation of the green water resource; and (c) assessing smart policy interventions aimed at increasing the total value of a system, which has clear merits for transboundary water management by identifying opportunities for benefit sharing between upstream and downstream riparian countries. The authors argue that the water value-flow concept can be improved by including the precipitation-shed concept to account for the origin of precipitation in a catchment. Moreover, they invite the scientific community to explore how the concept can be enriched by the incorporation of water quality and instream, social, cultural, and spiritual benefits, and to apply the concept in existing case studies in the emerging fields of socio-hydrology and water accounting.

3.2. Water and Global Food Production

The contribution of Mekonnen and Gerbens-Leenes [28] reviews current and possible future water footprints of global food production and its sustainability. They discuss how water footprint assessment of food production has developed in multiple directions. One direction of development concerns the consideration of supply chains, which developed from analyzing consumptive water use in national crop production and trade [3] to analyzing complex supply chains, particularly for animal products where feed crops, crop residues and grazing contribute to the embedded water appropriation [4,10,11,15]. Large differences in footprints of crop versus animal products emphasize the relevance of studying diets, while food losses and waste also contribute substantially to the global footprints of food. On these aspects, a wide body of international literature has emerged over the last decades. A second direction of development concerns the consideration of the sustainability of the water footprint of food production. Spatially explicit analyses put blue water footprints in the context of sustainably available water resources. Over half of the global blue water footprint of food production was concluded to be unsustainable [29]; the lion's share of unsustainable footprints are caused by only six crops and occur in only five countries. Mekonnen and Gerbens-Leenes conclude with an outlook of a sharply increased future water footprint, and with Arjen Hoekstra's policy suggestions to combat widespread unsustainable water use, applying water footprint caps, footprints or fair communal shares.

3.3. The Water-Energy Nexus

The contribution of Gerbens-Leenes, Vaca-Jiménez, and Mekonnen [30] sketches the importance of water footprint studies for the research area of water-for-energy. Studies by Peter Gleick [31] were the cornerstone of this research field. Water footprint analyses of energy production added a clear base of definition and terminology, with a focus on consumptive water use of bioenergy crops grown as feedstock for bioenergy production. This explicit focus and consistent usage of terminology is relevant in a field where water use may implicitly refer to either withdrawals or net losses. Water footprint studies have progressed from analyzing first-generation biofuels (bioethanol and biodiesel from sugar, starch, or oil crops) [12] to biofuels from cellulosic feedstocks, including residues or from algae. Water footprints of electricity covered fossil fuel-based generation as well as renewables [13], with specific attention on hydropower. Analyses are often hampered by the availability of data on industrial processes of, for instance, energy conversions. By now, water footprint assessment has made its way into the IEA World Energy Outlook [32]. Gerbens-Leenes, Vaca-Jiménez, and Mekonnen conclude by observing the clear scientific significance of water footprint studies in the field of water-energy-nexus research. Choices in energy generation go along with trade-offs between carbon footprints and water footprints, and these tradeoffs have become better understood.

3.4. Water Resource Use for Sustainable Healthy Diets

The contribution of Vanham [33] explores the role of water in sustainable healthy diets by reviewing current water footprint research on the water-food nexus and identifying future research directions. Emphasis is given to the importance of setting system boundaries—and being explicit about these. In most recent environmental footprint assessments in general and water footprint assessments of diets in particular, the supply chain of food products is described up to the farm gate. Other supply chain stages, such as processing, distribution and (supplier) energy inputs, are thereby often not included. While

Vanham recognizes the high information density of dietary water footprints, the limited data availability on specified supply chains with high spatio-temporal resolution constrains more detailed assessments. This point was raised by other contributions in this Special Issue as well and is a clear challenge for the water footprint community going forward.

Vanham goes on to describe progress in research of contextualizing dietary water footprints in terms of their equity, efficiency and impact. In particular, the use of the term impact seems to have multiple interpretations depending on the academic or policy discourse one takes as a starting point. Is impact restricted to water stress and scarcity? When is impact of a dietary water footprint low or acceptable? How do you measure impact in water footprint assessment versus, for instance, life cycle assessment, and why and when to choose which? These are relevant questions, particularly when addressed in conjunction with equity and efficiency criteria and concerning the wider footprint family of sustainable healthy diets.

3.5. Water Scarcity Management in Spain

The contribution of Aldaya, Garrido, and Llamas [34] discusses the evolution of virtual water and water footprint research in Spain since its introduction in 2005 and reflects on its contributions to national water policy debates. Analyses of virtual water trade, as introduced by Tony Allen [35], and water footprints, as introduced by Arjen Hoekstra [4], were added as innovative viewpoints in integrated water resources management [36], showing that water-scarce regions in Spain with expanding irrigation were net blue water exporters used to produce low-value crops. River basin studies using water footprint concepts, added the consideration of green and grey footprint components in discussing integrated and sustainable management in water planning. By now, water footprint analyses are integral components of river basin management plans in most river basins in Spain. In particular, footprint analyses provide criteria for prioritizing uses, allocating resources; they also guide cost recovery, assess impacts of grey water footprints, and support the economic characterization of virtual water flows. Aldaya, Garrido, and Llamas conclude that water footprint evaluations have been influential in informing decision makers in policy and business as well as consumers on the importance of water in all aspects of peoples' lives and in economy.

3.6. Understaning and Resolving Water Issues in China

The contribution of Zhuo, Feng, and Wu [37] reviews water footprint papers on China in both English and Chinese scientific literature. Chinese literature was found to focus on crop water footprints, diets, water resources assessment, and decomposition analyses; English literature is less focused on single topics, with the highest publication rates on water footprints in relation to urban households, life-cycle analysis, ecological and grey footprints and the water-energy nexus, and a specific spatial focus on the North China Plain. Studies on water footprint quantification have increased substantially in number and extended into the spatio-temporal specification of footprints and the extended inclusion of supply chains. Nevertheless, the variations in values for matching assessments is considerable while uncertainty analyses still are scarce. This uncertainty challenges the robustness of, for instance, the assessment of driving factors behind water footprint trends, including water-saving technologies, industrial restructuring, and water prices. Zhou, Feng, and Wu conclude that the further development of standards for water footprint accounting and impact analysis, including social and economic effects and uncertainty analysis, is needed for ample adoption of water footprint considerations in Chinese water policies.

3.7. The Water Footprint of the United States

The contribution of Konar and Marston [38] takes a deep dive into the body of literature on water footprint research pertaining to the United States. Listing over 100 publications that span across multiple angles and perspectives, their review first and foremost illustrates the wide and diverse uptake of water footprint research in this important geographical region. The US is a key nation both with regards to the global water footprint of production and consumption, as well as regarding its role in the global virtual water trade network. Few countries can boast such an impressive research coverage across production, virtual flow and consumption perspectives at such high levels of sectoral (agriculture, energy, industry), source ((unsustainable) surface water, groundwater, green water), commodity and/or spatiotemporal granularity of assessment. One of the main reasons for this successful assimilation, the authors identify, is the abundance of US-based data that is available to build upon. From the USGS's National Water Census [39] to the Commodity Flow Survey, many US-focused studies could not have been carried out without efforts across the institutional landscape to collect and collate high quality information.

Another take-away from Konar and Marston's [38] review is the importance of Arjen's labors of standardizing a terminology and methodology on water footprint assessment. Given the complexities involved in understanding local-to-global connections between water and society, adhering to a shared language may pre-empt at least one additional complicating factor. Konar and Marston readily acknowledge that as more detailed datasets become available and uncharted assessments become feasible (e.g., at the conflation of bordering concepts of other footprints' input-output methods or integrated assessment), new methodological challenges are emerging. It goes to show that the water footprint community, both within and beyond the United States, does not have to sit idle to advance new research lines.

3.8. Water Stress and Water Footprint Accounting

The contribution of Wang, Hubacek, Shan, Gerbens-Leenes, and Liu [40] clarifies key concepts in the evaluation of physical water stress in terms of water quality and quantity. Combatting water stress is adopted as an urgent goal in the Sustainable Development Goals [41], which call for clarity on how to measure water stress or scarcity. Relevant aspects are the consideration of green and blue water, acknowledging the role of water quality as well as environmental, economic and societal water demands; Wang, Hubacek, Shan, Gerbens-Leenes, and Liu [40] focus on metrics for physical water stress and accounting methods supporting operationalization and make a structured comparison of metrics suggested in literature. Three categories of water stress indicators are discussed (per capita availability, withdrawal-to-availability-ratio and water-footprint-to-availability-ration indicators), as well as two accounting approaches (top-down and bottom-up). As major issues and gaps in water stress research, they identify the lack of agreed-upon standards to quantify environmental flows, a consistent consideration of return flows, the consideration of outsourcing of water appropriation to other areas through water pollution and other teleconnections, and the overall lack of standardization in definitions and approaches.

4. Closing Statement

As close colleagues of Arjen Hoekstra, we are happy to be able to share the insights presented in the contributions to this special issue. Each of the invited contributors has clearly expressed his or her appreciation of the many contributions to science by Arjen and of the inspiration he brought about. Heartfelt responses by numerous collaborators and colleagues over the last year have exemplified dearly how he is and will remain to be missed in the academic and professional communities of water management and environmental science. For us, this is a bright inspiration to continue pursuing integrated approaches to water management with explicit attention on global dimensions and the enriching multitude of perspectives on water management.

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