HYDROLOGY IN A COUPLED HUMAN–NATURAL SYSTEM

Research, Innovation, and Practices

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The International Association of Hydrological Sciences (IAHS) is a nonprofit nongovernmental scientific organization. It is one of the eight constituent associations of the International Union of Geodesy and Geophysics (IUGG). IAHS has a long and well-known track record in undertaking a range of activities that aim to improve hydrological knowledge and practice globally (www.iahs.info). In 2003, IAHS launched a scientific decade 2003–12 on prediction in ungauged basins (PUB; Sivapalan et al. 2003), and the relevant research outcomes (Pomeroy et al. 2013; Hrachowitz et al. 2013) that were generated by this community effort clearly prove that the IAHS research initiatives play a leading role in shaping the evolution of hydrological science. The success of PUB motivated the IAHS to propose another new initiative for the scientific decade 2013–22, entitled "Panta Rhei—Everything Flows," to continue to collectively tackle the most exciting research challenges related to the water cycle, water risks, and water resources. As summarized by Montanari et al. (2013), the purpose of Panta Rhei is to reach an improved interpretation of the processes governing the water cycle by focusing on their changing dynamics in connection with rapidly changing climate and human systems. The practical aim of the IAHS scientific decade is to improve our capability to predict the dynamics of water resources to support sustainable societal development in a changing environment. To engage the international research and operational communities in this 10-yr Panta Rhei project, a 3-day planning conference, entitled "Hydrological Knowledge Innovation and its Practices in Developing Countries," organized by Southern University of Science and Technology (SUSTech) and Wuhan University, was held in November 2016 in Shenzhen, China.

FIRST INTERNATIONAL CONFERENCE ON HYDROLOGICAL KNOWLEDGE INNOVATION AND ITS PRACTICES IN DEVELOPING COUNTRIES

What: Approximately 80 experts from various disciplines, including hydrologists, meteorologists, and sociologists, and from all over the world, in particular from developing countries, met to share a common interest in the coevolution of the coupled hydrology–society system under global change.
When: 13–15 November 2016
Where: Shenzhen, China

The planned conference attracted a diverse group of experts in hydrology, meteorology, numerical modeling, atmospheric processes, data assimilation, observing systems, forecasting/prediction, economics, and social science. The perspective of the conference is to bring together scientists from all over the world in various disciplines that share a common interest in the coevolution of our coupled hydrology–society system under climate change as well as human impacts. Great attention was paid to the developing countries, in particular in the countries involved in the "One Belt, One Road initiative." The fundamental theme of this international conference related to hydrology, meteorology, climatology, and society mainly concentrated on their interconnections and their compound impacts on water resources. During the 3-day agenda

in Shenzhen, 29 scholars from 13 countries gave oral presentations at the conference, including a series of invited talks from leading scientists. Extensive discussions were made during and after the oral session. At the end of the conference, the "Shenzhen Declaration on Global Hydrological Science and Practice" (hereafter the Shenzhen Declaration) was promulgated, which carries the destiny to strengthen multidisciplinary collaboration. Immediately after the conference in Shenzhen, the launching meeting of the Chinese Working Committee (CWC) for the IAHS Panta Rhei was held on 16 November 2016 at Wuhan University, China. IAHS CWC gathered Chinese scientists in hydrology, meteorology, climatology, and social science and further promoted collaboration and exchanges with the international research community.

DISCUSSION. The purpose of this international conference is to improve our understanding of complex mechanisms within the water cycle in a coupled hydrology–society system, thus increasing water security in a changing environment. Coupled models were a central component of the oral presentation session, and challenges including meteorological input data, model initialization, coupling, temporal and spatial resolution, inherent systematic errors, and uncertainty quantification were also reported. In addition, several critical gaps were identified: 1) More sophisticated coupled models are necessary in order to depict a complex dynamic human–natural system. All forces of nature are connected and mutually dependent. Hydrology, meteorology, climate, landscape, ecosystem, and society are closely interwoven (Schwinning et al. 2008). Given the natural complexity of water and the natural overlaps among different systems, it emerged that the development of advanced coupled models is essential and will be the focus of the next decade in cross-disciplinary research (hydrometeorological–social analysis) with high priority. 2) Coevolution between systems (e.g., atmosphere, hydrosphere, and biosphere) must be accounted for in the research of a changing environment. Nothing is permanent except change; ecosystems can also evolve in a Darwinian sense and can adjust themselves to maintain crucial functions while the surrounding environment changes (Savenije and Hrachowitz 2017). The physical-based models, which take Newtonian theory to heart, should also hug the Darwinian theory. Coevolution assessment is also the main subject of the IAHS project Panta Rhei—Everything Flows. 3) Great attention should be paid to regions suffering heavy human-induced impacts. Human activities are exerting increasing impacts on the environment on all scales, outcompeting natural processes in many ways. We have now entered the Anthropocene, a geological epoch in which humanity's impact on Earth is profound (Crutzen 2006; Van Loon et al. 2016). Human activities (such as land-cover change, gray infrastructure construction, and urbanization) have deeply impacted the natural water cycles (Liu et al. 2013; Palmer et al. 2015). There are hot spots all over the world exposed to severe water problems including water shortages (Wada and Bierkens 2014), deterioration of water quality (van Vliet et al. 2016), water disasters [e.g., floods (Hirabayashi et al. 2013) and droughts (Prudhomme et al. 2014)], and ecosystem degradation. These areas are growing under global change (Veldkamp et al. 2017), which strongly threatens the world economy and global sustainability and intensifies the pressure on our planet. 4) Data scarcity is a critical problem especially in developing countries (particularly countries in Africa). Low density of observational stations (e.g., meteorological weather stations) and low quality of the collected data dramatically hamper the research in these areas. In addition to the aforementioned critical gaps, there are also some gaps that were reported by the participants during the oral session, such as extreme events and resilience, water conflict in transboundary rivers, limited governance capacity for water management in developing countries, and water resources vulnerability.

Hydrological knowledge plays a key role in understanding the water cycle and providing the basis for the integration of hydrological processes in the climate system and with human activity, for water security. Scientists brainstormed on hydrological innovation based on the available knowledge to meet the grand water challenges and to bridge the existing gaps. Critical gaps in existing coupled hydrology–society models can

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DOI:10.1175/BAMS-D-17-0193.1

In final form 1 October 2017

be addressed via creative use of observations and novel research in model development (e.g., the advancement of supercomputing). Innovative knowledge in hydrology will propel our understanding of the processes and interactions among different systems, thus improving the structural design of coupled models. Coevolution issues can be solved by considering model parameter transition (e.g., using dynamic root zone storage capacity instead of a static one in the hydrological module to capture the coevolution effect under climate change). Water scarcity in some regions can be mitigated through virtual water transportation (Zhao et al. 2015, 2016). Data scarcity is expected to be addressed via the development of more appropriate estimation methods (e.g., remote sensing techniques) for the region and by making use of the advancement of prediction in ungauged basins. It has been recognized that owing to the complexity of the challenges it is necessary to change the scientific research strategy from traditional individual research to large teams with diverse areas of expertise collaborating on common problems. In recognition of this, integrated frameworks are essential to conduct research across all the relevant disciplines.

To promote and strengthen the cross-disciplinary collaboration for water-related research in integrated frameworks, the Shenzhen Declaration was announced at the end of the conference. The attendees voted on the Shenzhen Declaration by a show of hands, calling for efforts to work out a multinational interdisciplinary cooperation framework in association with global hydrological, meteorological, and social scientists to promote hydrological knowledge innovation and practices in all countries, especially the countries of the One Belt, One Road initiative—China's modern-day adaptation of the ancient Silk Road trading route. China is expected to play a leading role in hydrological knowledge innovation in developing countries, to promote the personnel exchanges and international cooperation among different countries through technical training and policy counseling, to assist more developing countries in establishing national working committees of the IAHS scientific decade (Panta Rhei, 2013–22), and to promote the development of IAHS in developing countries.

Furthermore, beyond the scientific perspective of this IAHS Panta Rhei conference, the Chinese Working Committee for the IAHS Panta Rhei was also founded immediately after the scientific part of the conference. The launch meeting of IAHS CWC was held on 16 November 2016 in Wuhan. After the unveiling ceremony, participants including the president, the secretary general of IAHS, and the president of IAHS CWC shared their opinions on the history, development, and future visions of IAHS. China is expected to be the leader of this research community in developing countries to promote collaboration with the international hydrological community and to expand the international influence of China's hydrometeorological research.

OUTLOOK AND NEXT STEPS. The planning international conference enabled participants to identify critical gaps in progress, common scientific challenges, and research priorities in hydrology–society analysis. The conference also offered a structure to plan a new IAHS initiative to address current problems and to promote further development.

Solving water problems under a coupled human–natural system must be a joint obligation of environmental scientists, social scientists, engineers, policy makers, and a wide range of stakeholders. These realities motivate the scientists in this IAHS Panta Rhei conference to make a set of core recommendations to governments, communities, enterprises, water users and providers, and all other relevant stakeholders. The following issues are of paramount importance and shape the main content of the Shenzhen Declaration, which was approved by all conference participants:

1) There is a need to strengthen hydrological science through collaboration of scientists from different countries and disciplines and among scientists, engineers, policy makers, and stakeholders.
2) There is an urgent need for developing countries to significantly strengthen hydrological science and to guarantee water security to achieve the United Nation's Sustainable Development Goals.
3) Open access to hydrological and meteorological data is vital for hydrological research, and policymakers should work together with scientists to make this happen.
4) China should intensify its support to the development of hydrological science and the promotion of the Panta Rhei program in developing countries, particularly in the countries in the One Belt, One Road region and in sub-Saharan Africa.
5) In supporting the development of hydrological sciences, cooperation should be sought with existing regional capacity-building networks, such as WaterNet in southern Africa.
6) There is a need to develop a multinational and multidisciplinary cooperation framework with a concrete working plan in order to provide capacity building, monitoring equipment, remote sensing techniques, and free software packages to developing countries.

CONCLUSIONS. The consensus view from the conference was that the existing focus on water security has delivered undoubted benefits to people around the world, but equally, we need to consider wider sustainable development goals in the context of the global human–water system. The international research community can successfully contribute to achieving the ambitious goals of the IAHS Panta Rhei project by establishing clear priorities and multidisciplinary collaboration and pursuing far-reaching, coordinated scientific efforts using accessible and well-supported infrastructure, data, and models. Moreover, IAHS never sleeps. The next IAHS Panta Rhei scientific assembly, entitled "Water and Development: Scientific Challenges in Addressing Societal Issues," was held in July 2017, in Port Elizabeth, South Africa. The Second IAHS Panta Rhei International Conference on Water System Knowledge Innovation and Its Practices in Developing Countries will be held on 20–22 November 2017 in Gorgan, Iran. These events are important in promoting the development of water-related research and accelerating transformations toward sustainable development.

ACKNOWLEDGMENTS. This study was supported by the National Science Fund for Distinguished Youth Scholars (41625001) and the National Natural Science Foundation of China (41571022). Additional support was provided by the Southern University of Science and Technology (Grant G01296001).

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