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INVITED COMMENTARY

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Water sensor network applications: Time to move beyond the technical?

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1 | INTRODUCTION

We have observed a dramatic increase recently in the range and diversity of hydrological and water resources projects using low-cost sensor networks to collect data across space-time. By reviewing the latest sensing and wireless communication technologies and their applications, and our recent experience of implementing hydrological sensors in low and middle income countries (Mountain-EVO, 2017), we argue here that the research frontier for sensor networks has to move beyond purely technical considerations. This is because the scope of available low-cost modules (such as Arduino, Raspberry Pi, and Xbee) and inexpensive sensors now enables rapid development of robust sensor networks that are highly effective and easily assembled rather than having to be built from scratch. With a wide variety of functions and features, these modules can support customisation of hydrological monitoring networks for users that have widely different goals and aspirations.

"Non-technical challenges" concern how the implementation of sensing, information, and communication technologies can be transformed into applications that meet contemporary societal challenges, such as water resources management (Aqeel-Ur-Rehman, Islam, & Shaikh, 2014), disaster resilience building (Mao et al., 2017), and sustainable development (Buytaert et al., 2014). It is increasingly evident that these societal challenges should play a more important role than technological considerations in evaluating successful applications of information and communication technologies (ICTs). Nonetheless, these non-technical aspects continue to be largely overlooked by hydrologists and sensor network developers.

In this commentary, we gather current views from the hydrological sciences community on water sensor network applications and distil-out the key technical and non-technical challenges, from which we contest that successful applications of hydrological sensors require further research, not only on technology itself but also on sociocultural and governance aspects.

2 | CURRENT PERSPECTIVES @AGU2017

To bring these issues to the attention of the hydrological community, and to improve our understanding of current prevailing attitudes and opinions to the development and use of sensor networks in the water sector, we presented an interactive poster on this theme at the 2017 American Geophysical Union (AGU) Fall Meeting. The AGU is the largest conference in the Earth and space sciences, regularly attracting more than 20,000 attendees from around the world (AGU, 2017).

The poster was scheduled in the MacGyver Session on December 14, 2017, an annual poster event for promoting innovative environmental data acquisition and transmission solutions (Hut et al., 2016). As well as being listed in the AGU's official programme website and mobile app, we also advertised the poster before the presentation through our Twitter account (@freshwaterflows), inviting conference attendees to join the presentation and conversation. The poster was set up at 8 a.m. The presenter (F. Mao) introduced the study and discussed its implications with the audience from 8 to 11 a.m. The poster remained on display until 6 p.m. when the afternoon session ended. A summary of technical and non-technical challenges was presented interactively: The audience was encouraged to place round stickers next to the issues or challenges they felt were most important, or to leave comments and feedback using post-it notes (see Figure 1).

3 | EMERGENT TECHNICAL AND NON-TECHNICAL CHALLENGES

Based on the feedback from the AGU community, challenges for water sensor network applications were identified. Interestingly, although the poster focused on "neglected non-technical perspectives," most of the comments were about the technology itself. Conventional technical features and challenges included low-cost, battery life, and power efficiency; wireless connections; real-time data acquisition and processing, precision and accuracy; robustness and reliability; physical and information security, and sensor network optimisation. The non-technical challenges that were flagged are summarised in Table 1 along with posted example questions.

Feedback showed that all the technical features were deemed important, with wireless communication being the most popular. However, in practice, there are always trade-offs and compromises in choosing the features for sensor network design. One participant commented that finding a "silver bullet" technological solution addressing multiple technical challenges was highly unlikely—that is, one that could be simultaneously power efficient, cheap to obtain, and have wireless communication. With limited resources (e.g., funds and human capacity), certain features tend to be selected to maximise the overall performance of sensor networks. For example, the low-cost sensor is usually regarded an alternative solution to collect environmental data in an affordable way, while compromising data precision and accuracy. Compared with the conventional and professional sensor stations, the low-cost solution can significantly increase the coverage area of monitoring or the number/density of sensor nodes (Hart & Martinez, 2006). However, the size, number, and density can also depend on the expected duration of monitoring activities. One audience member noted that long-term monitoring with fewer nodes could be more valuable and useful than short-term monitoring with a wider coverage in some situations.

Ultimately, these trade-offs and compromises are determined by the goals and sociotechnical contexts of end-users. For example, early warning systems may have higher demand on technical functions such as real-time data processing and communication than other applications such as scientific data collection or water resources management in general. In addition, analysing user demands is clearly essential. For example, one comment pointed out that the understanding of "low-

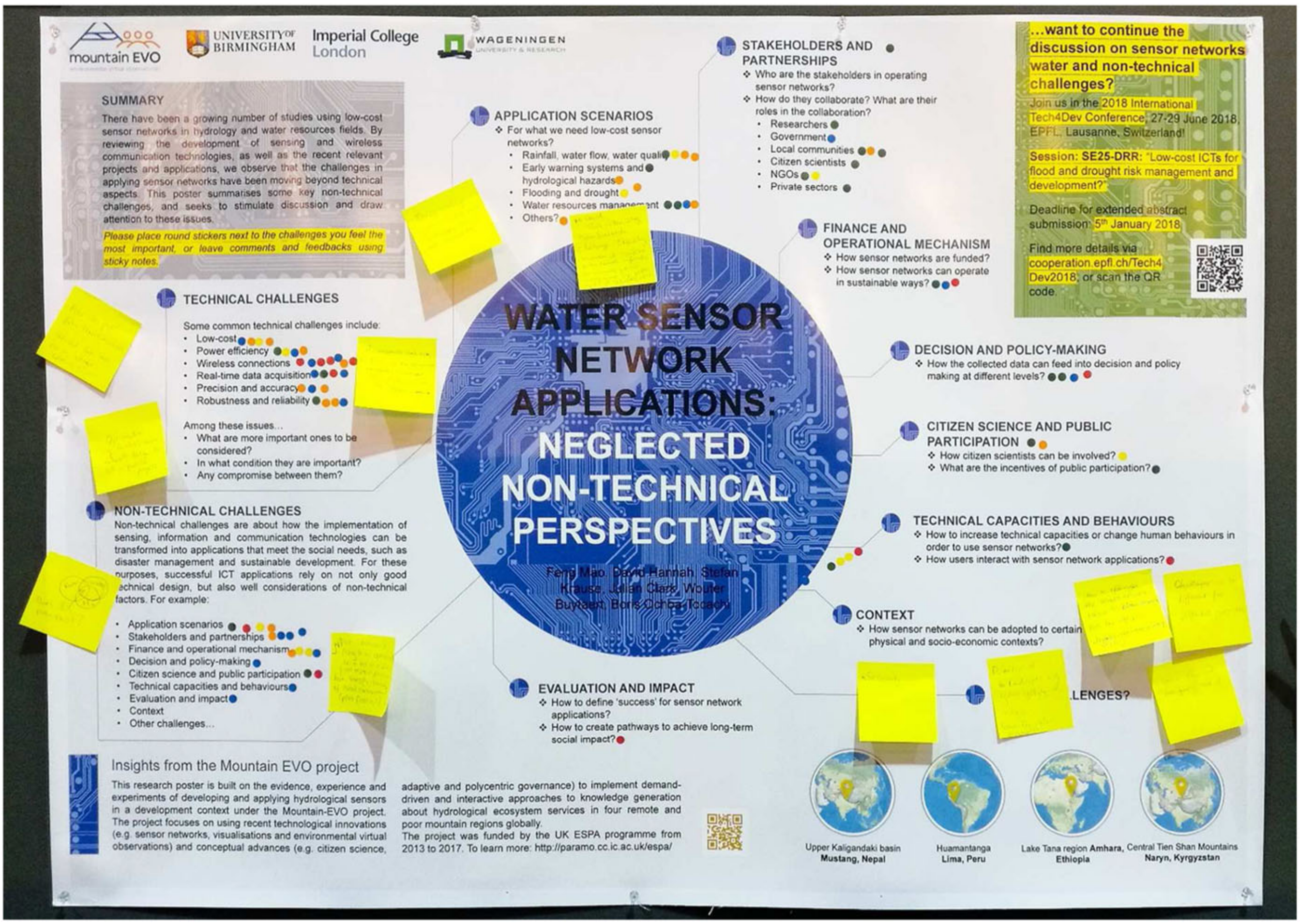

FIGURE 1 Commented poster at the end of the day. Round stickers were placed next to the issues that the audience considered important. Round stickers with different colours carry equal significance. Feedback was left on the poster using yellow post-it notes

TABLE 1 Non-technical challenges and example questions

Application scenarios ● What do we need low-cost sensor networks for?
Stakeholders and partnerships ● Who is involved in operating sensor networks and for what purpose? ● How and why do these stakeholders collaborate? What are their collaborative roles?
Citizen science and public participation ● How can citizen scientists be involved? ● What incentives are there for public participation in sensor networks?
Context ● How can sensor networks be adapted to different physical, socio-economic and sociotechnical contexts?
Technical capacities and behaviours ● How and in what ways might we increase technical capacities or change human behaviours in order to use sensor networks? ● How do users operate and interact with sensor network applications?
Decision and policy-making ● How can collected data feed into decision and policy making at different levels?
Finance and operational mechanism ● How should sensor networks be funded? ● How can sensor networks be made more financially and politically sustainable?
Evaluation and impact ● How can we define and evaluate ‘successful’ sensor network applications? ● How can we create pathways to achieve long-term societal impact through sensor network applications?

cost” differs among user groups. Scientists may think $100 is cheap but that may be unaffordable in remote rural regions without external supports. Similarly, changing the target group from scientists to local community members can alter potentially sensor network design. This suggests that we need to change our sensor network design practices from a technical-centred approach to purpose-oriented one with consideration of non-technical factors and explore the “demand side” of the water sensor network applications.

Challenges beyond data collection were highlighted by the poster audience. It was agreed that there is a wide gap between collected and available hydrological data. Most attention has been paid on how to collect, process, and display hydrological data—instead of the further downstream processes in the work flow, such as how the data can be used for environmental decision and policy making for different stakeholders and at different scales. These under-researched activities have great potential to increase the social impacts of water sensor network applications. For example, in data scarce regions, especially remote areas, there is a pressing need to answer how newly obtained hydrological data can help indigenous communities to understand local hydrological processes (i.e., water resources and hydrological disasters) and create pathways to future sustainability and resilience (Mao et al., 2017; Paul et al., 2017).

Last but not least, the audience was aware that most scientist-led sensor network projects are restricted by the short-time scale of their funding. Monitoring activities usually stop almost as soon as the research project finishes. This suggests that when designing sensor network applications—for different purposes, scenarios, and users other than research—alternative operational mechanisms are required to be developed to achieve sustainability. Example issues include new funding schemes, innovative governance model, and new stakeholder engagement including citizen scientists/participatory approaches.

4 | MOVING BEYOND THE TECHNICAL

We believe that successful applications of hydrological and water resource sensors require further research not only on technical but also crucially on sociocultural and governance factors. Our poster study offered a means of testing this proposition among the scientific community, while drawing people's attention to this neglected issue. Addressing this issue comprehensively now requires sensor network researchers and developers to work closely with a broader range of stakeholders than they are accustomed to, including policy makers, NGOs, local community members, and private sector representatives to identify practical real-world challenges and demands that the academy may not yet be aware of. Furthermore, it is likely that hydrologists and sensor engineers will need the support of social scientists in fields such as environmental governance, international development, public policy, and socioeconomics to broaden their grasp of the importance of sociocultural contexts and sociotechnical regimes to sensor network development. Interdisciplinary studies that are nourished by these knowledge domains will be in a better position to provide solutions to non-technical problems, and answer questions such as how ICT applications can help and support poor and marginalised communities and social groups (Heeks, 2008).

This discussion on non-technical aspects of water sensor network applications will be continued in such events as the International Tech4Dev Conference in Lausanne, Switzerland in June 2018 (EPFL, 2017). We hope this commentary will stimulate some debate within and beyond the hydrological community on neglected non-technical perspectives on sensor networks.

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