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Editorial: Water data networks: foundations, technologies and systems, implementations, and uses

INTRODUCTION

At the time of this special issue, we are faced with an unprecedented increase in the volume of hydrological data. More hydrological data are being collected today than ever before, at faster rates, creating a veritable data deluge. Fueling this deluge are new approaches to data collection, including improved devices such as cheaper and more efficient sensors, as well as innovative strategies such as citizen participation in which data are gathered by the broader public. Apart from these enhanced data supply mechanisms, the data deluge is also being fueled by a reciprocal increase in the demand for data, from both customary and non-traditional users. The increased demand is stimulated to no small degree by raised expectations for data availability, themselves a result of new methods and policies for accessing and analyzing enormous volumes of data. For example, open data policies are influencing the liberation of data from closed repositories, new technological standards are driving improved interoperability via standards for online data access and content, while scalable mechanisms for massive data storage and computing, primarily cloud-based, are allowing more data to be processed faster by more users in a greater variety of situations than ever before. As a result, users are expecting data and related applications to be available immediately, easily, openly, and in greater quantities.

Positioned within this overall hydrological data milieu, this special issue concentrates on a key enabler for water data availability: the water data network. Water data networks address access issues in the data supply chain: water data have traditionally been difficult to find, get, and use, because they are fragmented across numerous data providers distributed geographically, and because of heterogeneity in the access, storage and licensing mechanisms. This is particularly concerning for many current scientific and societal questions, such as those related to climate, energy, and hazards, to name a few, which require a diversity of data from multiple sources. To overcome this data access barrier, data suppliers have been linking multiple data sources into combined networks that provide a level of uniformity to both the access and content of the data. This applies as much to the development of an individual network, such as a monitoring network, in which multiple sensors are connected, as it does to a nested network of networks, in which multiple individual networks are federated. In both cases, new technologies and standards are implemented to link data sources and ease access to the data, making it available for wider uses. For example, the development of an individual water monitoring network might incorporate global standards for transmitting the data to a central database, and the database might deploy global standards for its online access, which enable the data to be readily incorporated into other networks, cloud-based repositories, or various software systems that serve a variety of real-world applications.

This special issue is concerned with all aspects of water data networks, encompassing their design, construction and use. In particular, the nine papers address: (1) foundational components for the interoperability of data within such networks; (2) specific technologies and systems that might be used to construct and enhance a water data network; (3) examples of actual water data networks implemented by significant agencies; and (4) examples of the use of water data networks to address important scientific and societal concerns. These contributions come in response to an open call for papers that followed the 11th International Conference on HydroInformatics, held during the 17th–21st of August 2014 at the City University of New York. Two of the papers (Brodaric *et al.* 2016; Yu *et al.* 2016) are significantly enhanced contributions from the conference, while the rest are independent submissions.

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Interoperability foundations

Two foundational papers address middleware components that contribute to the interoperability of water data networks: a component for data brokering and another for management of units of measure. Yu *et al.* (2016) present (i) a new metadata ontology that interconnects organizations, datasets and associated web services, as well as (ii) an associated brokering strategy that uses the ontology and linked-data approaches to enable the seamless query and retrieval of data from heterogeneous environmental data repositories. An important aspect of such data brokering is the management and conversion of units of measure, which can be facilitated by the HydroUnits Python-based software developed in the paper by Celicourt & Piasecki (2016). HydroUnits is tailored for hydrological time series, although it is general enough to accommodate a wide range of applications that use the IEEE 1451 standards for units of measures.

Technologies and systems

Two papers from the Consortium of Universities for the Advancement of Hydrologic Sciences Inc. (CUAHSI) discuss the construction and embellishment of water data networks. In the first paper, Sadler *et al.* (2016a) describe a recipe for the development of low-cost environmental sensor networks using open source components and mass-produced products, as well as the integration of the collected data into open standards-based servers, such as CAUHSI's HydroServer. The second paper by Sadler *et al.* (2016b) combines the social media functionality of HydroShare with CAUHSI's Hydrologic Information System (HIS), resulting in a platform for discussion and collaboration around hydrologic data. The platform allows scientists to make and save comments about HIS time series data, enabling for example discussion of interesting data points and the brainstorming of follow-up actions.

Implementations

Three papers present large international water data networks from different perspectives. Brodaric *et al.* (2016) discuss how the Canadian and US groundwater data networks are made interoperable within each country, as well as between the two countries, through the deployment of similar but not identical interoperability infrastructures, and the adoption of global standards and bilateral protocols at five levels of interoperability. Blodgett *et al.* (2016) describe the state of the US Geological Survey's progress on water data integration and distribution, and Dahlhaus *et al.* (2016) present the results of a user survey of a groundwater data network and visualization portal for the Australian state of Victoria; the survey clearly illustrates that the impact of such networks can be significant and can alter various practices amongst a wide range of stakeholders.

Uses

The final two papers show how water data networks can be incorporated within larger systems for major societal impact. Pumo *et al.* (2016) describe the SESAMO early warning system for rainfall-triggered landslides in Sicily, Italy. The system relies on multiple sensor networks, such as those for rainfall and soils, that feed data to other system components using international data standards. This enables real-time analysis of environmental conditions and rapid warning of predicted landslide events. The paper by Espinoza-Dávalos *et al.* (2016) demonstrates the benefits of analyzing large land surface model outputs for major drought and flooding scenarios, with the outputs made available as time series from a combination of web-services and cloud infrastructure.

While the growth of water data networks, and their uses, has been rapid and widespread, from local to regional to global in nature, there remain many further opportunities for advancement and innovation. On the technology side, the adoption of linked-data approaches is still in early stages and found mostly in research-oriented systems; the migration of such approaches into operational environments seems promising (as evident by the paper of Yu *et al.* 2016). On the side of operational deployment, developments have been dominated by major data providers, but there is room and need for water data networks to be formed at national and regional scales. Indeed, the aggregation of networks across all scales is a likely direction for the data supply component of next generation water accounting and monitoring systems, particularly those intended for

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large areas (e.g. continental, global). Lastly, on the usage side of things, the potential uses for the vast amounts of data provided by water networks remains largely untapped, and it is by the degree of realization of this potential that such networks will likely be judged in the future.

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