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Water Data Systems: Science, Practice, and Policy

Melinda Laituri and Faith Sternlieb

Colorado State University

Water agencies, governmental organizations, and non-governmental organizations accountable for water use, development, and conservation are dealing with ways to address changes in water data collection, maintenance, storage, visualization, and communication. As demand for water resources and variability of water availability increases, water data are essential to monitoring changes and finding solutions. Coupled with other data efforts to enhance "big data" and serve critical environmental issues, water data reveal the complex data-scape that demands streamlined data standards across scientific communities where data processing systems are fragmented due to multiple sources and methodologies, limited data sharing, and incomplete data coverage. With a better understanding of some of the discrepancies in the science, practice, and policy of water data systems, we need to consider and implement innovative ways to foster stronger water data sharing arrangements. This special issue on Water Data explores the science, practice, and policy of water data systems, provides examples in which data integration has been successful or ineffective, and explores the technological frontier of water data systems.

What are Water Data?

"Water data" is a diverse set of information that address the physical, environmental, ecological, social, economic, cultural, and political parameters of water use, availability, and accessibility. These data can be divided into general categories that include:

- Water availability: This includes metrics of precipitation, temperature, surface and still water amounts and flow, snow and ice, groundwater, and soil moisture (Willardson, this issue).
- Water use: Use refers to human consumptive uses (i.e., per capita), use by sector (i.e., agriculture, industry), environmental use (i.e., evapotranspiration rates), and ecosystem services (Rebelo et al., this issue; Martin et al., this issue).
- Water quality: Quality parameters for both surface and groundwater essential for the regulatory process.
- Water extremes: Hazard and disaster data that include drought and flood monitoring, storm watches and reports, and weather data (Ralph et al. this issue).
- Water indicators: Usually linked to some aspect of human or environmental health, indicators integrate other data to provide a metric for water poverty, sustainability, and human well-being (Sternlieb and Laituri 2010).

These catagories are not all inclusive and do not capture all the human dimensions of water data that impact the delivery and sharing of data as well as the infrastructure for data systems.

While the water sector is data-rich, the extent, accessibility, and availability of water data is unevenly distributed across the globe. These challenges make it difficult to compare results from water data studies across global regions and river basins in addition to the difficulty decision-makers have in managing water resources in data scarce places. Water data are a complex mix of a multitude of data formats that include spreadsheets, satellite images, geospatial databases, and photographs. Other data types include measures of climate change from climatological models, hydrological modeling outputs at local, regional, and global

scales, and processed remote sensing data or satellite images (i.e. metrics of evapotranspiration, change detection studies on water flows and flux).

Global datasets of water supply and water-related resource issues are generally better than local and regional water data. Federal agencies such as the United States Geological Survey house comprehensive datasets on national water resources regarding stream flow, groundwater supplies, precipitation, water quality, and lakes and reservoirs (National Water Information System, http://waterdata.usgs.gov/usa/nwis/rt). Many thematic global datasets are also available online and are useful for developing world users, such as those provided by academic institutions (e.g, Center for International Earth Science Information Network of Columbia University). Many of these datasets are available via the Internet; however, understanding how to download the data or process and analyze the data is not as clear, despite efforts to create help sheets, useful tips, and frequently asked questions. Additionally, water data are not easily scale-able; assumptions cannot necessarily be made from data analyses at the global scale to those at a local scale.

Due to the complexity and challenges associated with water data, determining ways to construct integrated datasets are needed. Increasingly, computing capabilities allow us to examine large amounts of data. Forecasting, predicting, and modeling water availability across spatial scales is essential for future water planning. Integration of existing data can be improved by coordinating ongoing data collection activities, enhancing interoperability, and ensuring consistency.

Data Integration

Due to the multi- and inter-disciplinary challenges of water resources management, there is a need for greater integration of water data. Characteristics of data integration include the ability to cross spatial scales from local to regional to global, utilization of common data formats to ensure interoperability between datasets, and establishing linkages between science and applications. Results of data integration create shared information for dissemination and training products, new assessment tools to meet collective needs, and decision support systems for analysis and forecasting. Integrated datasets create cross-sectoral links to improve water stewardship that is inclusive of human and ecological needs.

Methods to integrate data are challenging. The need for integrated data that address myriad aspects of water resources is paramount. Comprehensive water data increasingly include satellite imagery and remotely-sensed data to create time series and capture local and regional scale products. Complementing such activity is the need to establish terrestrial networks for the validation of remotely-sensed data.

Water data are essential for planning, policy, and prediction. Decision-making is dependent upon water data that can provide real time information about weather patterns, consumption needs for agriculture on an annual basis, assessing competing uses for scarce water resources, hydrologic modeling after disastrous fire events, and infrastructure needs for water conveyance and storage structures.

Issue Overview

The papers selected for this special issue address the key issues associated with water data across the science, policy, and data management arenas. The authors that are represented in these papers come from diverse organizations representing both governmental and nongovernmental agencies from national and global perspectives, including the Western Governor's Association, the U.S. Geological Survey, the International Water Management Insitute and a broad geographic range of academic institutions. The first article in this issue, "Past, Present, and Future of Water Data Delivery from the U.S. Geological Survey", by Robert M. Hirsch and Gary T. Fisher, presents an overview of the water databases managed by the U.S. Geological Survey. Tracing the changes in water data availability from pre-internet to the present, this paper documents the delivery of real-time information of water parameters, the development of web-based mapping applications, and the creation of mobile applications of current hydrologic conditions.

This is followed by Ralph et al. "A Vision of Future Observations for Western U.S. Extreme Precipitation and Flooding" that provides a vision for tracking, predicting, and managing the impacts of major storms across the U.S. west. A description is provided of a comprehensive monitoring network for rain,

snow, snowmelt, flood, and hydrometeorological parameters that includes terrestrial and oceanic stations to create integrated datasets for scientific analysis and decision support assessments.

The third paper in this issue, "WaDE: An Interoperable Data Exchange Network for Sharing Water Planning and Use Data", by Sara G. Larsen and Dwane Young, discusses the development of the Water Data Exchange (WaDE) to enhance water planning. The article emphasizes the "nuts and bolts" of data exchange through proposing a governance structure, common formats, database development, and data delivery for U.S. western states. This approach may provide a template for future projects across the globe to develop mechanisms for getting water data in the hands of water planners more effectively.

Satellite imagery has become an essential source of derived water data. Willardson's "Landsat Themal Infrared Imagery and Western Water Management" describes the important contributions of Landsat imagery to measuring and monitoring water uses in the U.S. west. Situating his topic within the complex context of U.S. western water law, he describes multiple applications of thermal infrared sensor to water management. Such data collection techniques have significant implications for cost-savings for data collection and scientific progress in new analysis techniques.

The fifth paper in this issue, "Integrated Water Data and the Quest for Holistic Environmental Flows Management", by David M. Martin, Dylan Harrison-Atlas, Nicholas A. Sutfin, and N. LeRoy Poff, situates the need for socio-ecological water data within the framework of environmental flows. Science, data integration, and policy all intersect in an approach to provide a holistic framework for freshwater system management. Socio-ecological water data assimilation is recommended to develop a systematic approach to fill knowledge gaps and inform decision makers on complex water planning.

John Braden's article, "Social Observation for Sustainability Science about Water", sets a provocative tone by challenging the research community to consider how to collect data that support sustainability science defined as the interactions between human and natural systems. Braden provides two examples regarding water quality and environmental attitudes and behaviors that demonstrate the challenges of coupled human-nature research and the need for comprehensive data.

The article is followed by Gallaher and Heikkila's paper entitled, "Challenges and Opportunities for Collecting and Sharing Data on Water Governance Institutions." This paper examines 33 water governance organizations' websites for publically available datasets specifically focusing on outcome information of institutional mandates, objectives, and goals. Their findings reveal the on-going problem of publically available data on water governance institutions, yet another data integration issue.

The last paper in this collection is "Determining the Dynamics of Agricultural Water Use: Cases from Asia and Africa", by Lisa-Maria Rebelo, Robyn Johnston, Poolad Karimi and Peter G. McCornick. While the other papers focused on the United States in general and the U.S. west specifically, this paper addresses international water data needs with a specific emphasis on regional watersheds in developing countries. The need for comprehensive data at the regional and local scale cannot be overstated for holistic water planning for agricultural water management.

The suite of papers address critical issues of water data and the problems associated with comprehensive, integrated datasets for water planning and management. The explosive trajectory of technology sets the stage for an interesting future for data collection, development, and dissemination. Challenges associated with the need for holistic datasets at the local and regional scale for developing countries, however, remains a critical issue. Metrics for sustainable water management, developing integrated datasets, and understanding outcomes of institutional water governance are all arenas for further exploration. Next steps for water data include the development of a program for collaboration between existing projects and activities to facilitate a community of practice, to share best practices and lessons learned, and to raise awareness of the multitude of water-related activities that are being undertaken to create appropriate water data.

References

Sternlieb, F. and M. Laituri. 2010. Water, Sanitation, and Hygiene (WASH) Indicators: Measuring hydrophilanthropic quality. *Journal of Contemporary Water Research & Education* 145(1): 51-60.