Journal of Hydrology 518 (2014) 267–277

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Reviewing innovative Earth observation solutions for filling science-policy gaps in hydrology

Anthony Lehmann [a,b,*], Gregory Giuliani [b,c], Nicolas Ray [b,c], Kazi Rahman [a,b], Karim C. Abbaspour [d], Stefano Nativi [e], Massimo Craglia [f], Douglas Cripe [g], Philippe Quevauviller [h], Martin Beniston [b]

[a] University of Geneva, Forel Institute, Battelle – Building D, 7 route de Drize, CH-1227 Carouge, Switzerland
[b] University of Geneva, Institute for Environmental Sciences, Carouge, Switzerland
[c] United Nations Environment Programme, Global Resource Information Database, Geneva, Châtelaine, Switzerland
[d] Eawag, Swiss Federal Institute of Aquatic Science and Technology, Duebendorf, Switzerland
[e] Italian National Research Council (CNR-IIA), Florence, Italy
[f] European Commission, Joint Research Centre, TP262, Via Fermi, Ispra 21027, VA, Italy
[g] Group on Earth Observation secretariat, Avenue de la Paix, 7Bis, CP2300, 1211 Geneva 2, Switzerland
[h] Vrije Universiteit Brussel, Faculty of Engineering, Department of Hydrology and Hydraulic Engineering, Pleinlaan 2, 1050 Brussels, Belgium

ARTICLE INFO

Article history:
Available online 2 June 2014

Keywords:
Hydrological modeling
Climate change
Data sharing
Interoperability
Data processing
Decision making

SUMMARY

Improved data sharing is needed for hydrological modeling and water management that require better integration of data, information and models. Technological advances in Earth observation and Web technologies have allowed the development of Spatial Data Infrastructures (SDIs) for improved data sharing at various scales. International initiatives catalyze data sharing by promoting interoperability standards to maximize the use of data and by supporting easy access to and utilization of geospatial data. A series of recent European projects are contributing to the promotion of innovative Earth observation solutions and the uptake of scientific outcomes in policy. Several success stories involving different hydrologists' communities can be reported around the World.

Gaps still exist in hydrological, agricultural, meteorological and climatological data access because of various issues. While many sources of data exists at all scales it remains difficult and time-consuming to assemble hydrological information for most projects. Furthermore, data and sharing formats remain very heterogeneous. Improvements require implementing/endorsing some commonly agreed standards and documenting data with adequate metadata. The brokering approach allows binding heterogeneous resources published by different data providers and adapting them to tools and interfaces commonly used by consumers of these resources.

The challenge is to provide decision-makers with reliable information, based on integrated data and tools derived from both Earth observations and scientific models. Successful SDIs rely therefore on various aspects: a shared vision between all participants, necessity to solve a common problem, adequate data policies, incentives, and sufficient resources. New data streams from remote sensing or crowd sourcing are also producing valuable information to improve our understanding of the water cycle, while field sensors are developing rapidly and becoming less costly. More recent data standards are enhancing interoperability between hydrology and other scientific disciplines, while solutions exist to communicate uncertainty of data and models, which is an essential pre-requisite for decision-making. Distributed computing infrastructures can handle complex and large hydrological data and models, while Web Processing Services bring the flexibility to develop and execute simple to complex workflows over the Internet. The need for capacity building at human, infrastructure and institutional levels is also a major driver for reinforcing the commitment to SDI concepts.

1. Data sharing in hydrology

Water is a fundamental natural resource and is critical for the well-being of individuals (e.g. health, ecology, economic development) (WWAP 2012). However, shifts in balance between an

* Corresponding author at: University of Geneva, enviroSPACE Lab., Battelle – Building D, 7 route de Drize, CH-1227 Carouge, Switzerland. Tel.: +41 76 391 77 65.
E-mail address: Anthony.Lehmann@unige.ch (A. Lehmann).

http://dx.doi.org/10.1016/j.jhydrol.2014.05.059
0022-1694/

ever-increasing demand and dwindling supply of water has resulted in new competitive pressures, and also has had a negative influence on water quality (Lecca et al., 2011). Effective and efficient water management requires coordination of actions, one of them being access to, and provision of, reliable data and information (e.g., state of the resources, changes, pressures) and the capacities to interpret correctly and meaningfully this information (Gerlak et al., 2011; Roehring, 2002). Water management and hydrological modeling intrinsically require integration of data, information and models due to their interdisciplinary complex nature (Argent, 2004; Buytaert et al., 2012; Papajorgji, 2005).

Currently, it is recognized that the lack of systematic monitoring and access to reliable time-series on environmental and socio-economical data, suitable for statistical analyses, are a major barrier to effective and efficient informed policy-making (UNEP, 2012). This problem has been recently addressed by several EU funded projects related to water (e.g. ACQWA, enviroGRIDS, GEOWOW) (Fig. 1). They all highlight the main obstacle to attaining the objectives of these projects (to guide and inform policy) that is the lack of access and availability of data (Beniston et al., 2012). This is also illustrated by research developments in the field of chemical monitoring and discussions about standardization needs in support of the wide-scale river basin monitoring programmes required by the Water Framework Directive (Quevauviller et al., 2007). In summary, many policy-relevant research areas are still facing the problem of readily and timely access to, and exchange of, data.

1.1. Spatial Data Infrastructure (SDI)

Supported by the latest technological advances in Earth observation and Web technologies, Spatial Data Infrastructures (SDIs) have been developed and implemented at an accelerated pace recently, both at regional and national levels, with the long term vision of creating a global SDI. The benefits of SDIs have been analyzed and reported extensively (Campagna and Craglia, 2012; Heumesser et al., 2012), as they allow for trans-sectorial and trans-national sharing of, and access to, geospatial data. In addition, their assimilation (consumption) in novel and inventive software applications has provided a wide range of social, economic and environmental benefits. For achieving these purposes, SDIs provide a suite of services for data publishing, discovery, gathering and integration, which enable interoperability of the different components involved. Therefore, the concept of SDI has been developed to facilitate and coordinate the exchange and sharing of geospatial data, encompassing data sources, systems, network linkages, standards and institutional issues involved in delivering geospatial and information from many different sources to the widest possible group of potential users. The objective of an SDI is to provide a framework for incorporating different databases, ranging from the local to the national/regional, into an integrated information highway in order to make effective use of the geospatial data needed by a particular community.

Interoperability is the essential condition for developing an open science framework, allowing scientists and researchers to publish, discover, evaluate and access data (Vaccari, 2012). Current technologies are suitable to match these requirements only if open software interfaces and standards are established, allowing these technologies to interoperate at a global scale (McKee, 2010). The Open Geospatial Consortium (OGC), the leading international voluntary consensus geospatial standards development organization, aims to develop and provide such standards enabling communication and exchange of information between different systems with differing operational software.

The OGC is providing a suite of standard specifications to search and discover geospatial resources (Fig. 1). These resources can be maps provided via Web Map Services (WMS), vectors and raster data published respectively as Web Feature Services (WFS) and Web Coverage Services (WCS), or processing algorithms exposed as Web Processing Services (WPS). Data and services can be documented through International Organization for Standardization (ISO) 19,115 (resource metadata), 19,139 (metadata encoding) and 19,119 (service metadata). These standards are complemented by the OGC Catalog Service for the Web (CSW) specification defining an interoperable interface to publish, discover, search and query metadata.

Metadata are an essential component of the information chain as they enable users to understand the provenance, content, and quality of data. This in turn allows the user to interpret them

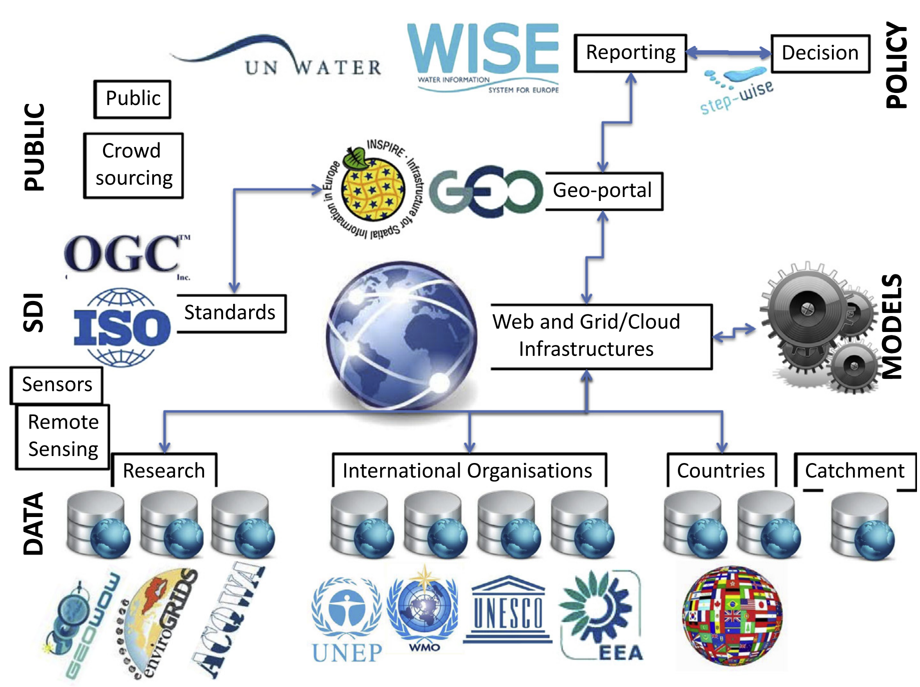

Fig. 1. Selected projects and main international initiatives contributing to the development of water related Spatial Data Infrastructures.