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Perspectives from a water research institute on Knowledge Management for Sustainable Water Management

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Introduction

Sustainable Water Management (SWM) is a domain in which the aspects of *knowledge as a public good* (van Kerkhoff, 2013) are intuitively obvious. This derives from the fact that water management has been a core responsibility of civil society throughout history (Mays, 2010; Sedlak, 2014). Here, water management is defined broadly to encompass:

- Water supply and use (e.g., for drinking water, irrigation, aesthetics, fire protection, etc.).
- Water resources protection (e.g., for fisheries, recreation and provision of other ecosystem services).
- Management of watercourses and infrastructure (e.g., for navigation, flood protection, water and wastewater conveyance).

With this broad definition, water management must necessarily address competing uses and interests, taking into account natural, technical and societal factors (Hering & Vairavamoorthy, 2017). Whether water management can be characterized as sustainable (in a given context) will depend on whether deficits in one type of factor, such as limited natural water availability, can be offset by other factors (e.g., demand management and/or infrastructure for water storage). Conversely, sustainability is unlikely to be realized when deficits are aggravated by, for example, limited human capacity and economic resources. Meaningful approaches to SWM can only be identified and implemented in local and regional contexts (Hering *et al.*, 2015).

A huge, even overwhelming, array of knowledge is available that is highly relevant to SWM. This knowledge, which derives not only from the natural, social and engineering sciences but also from practical experiences in water management, reflects a massive investment of resources on the part of civil society. Having access to SWM-relevant knowledge could allow society to conserve its resources by using (rather than re-inventing) existing knowledge. It might also be possible to avoid unintended, adverse consequences by understanding past failures and, as well, the factors that contributed to past successes and might limit their replication under different conditions. In addition, tapping SWM-relevant knowledge could contribute to understanding what conditions would be amenable to “leapfrogging” as compared with those that are likely to require the progressive development of systems or approaches for water management (Briscoe, 2011). Ultimately, the goal of improving access to SWM-relevant knowledge would be to provide the most useful knowledge base for decision-making (Cash *et al.*, 2003; Cornell *et al.*, 2013; Hering, 2015; Martinuzzi & Sedlacko, 2016; van Kerkhoff, 2013; van Kerkhoff & Lebel, 2006; van Kerkhoff & Szlezak, 2016). This need is especially pressing in light of the commitment of the nations of the world to achieve the Sustainable Development Goals by 2030 (UN, 2015). Water supply, sanitation and the quality of receiving waters are addressed explicitly in Goal 6 “Ensure access to water and sanitation for all” and also in the Goal 11 targets to reduce the impact of water-related disasters and the adverse per capita impacts of cities.

In this chapter, issues of Knowledge Management (KM) as applied to SWM are examined from the perspective of a single organization, the Swiss Federal Institute of Aquatic Science and Technology (Eawag). Constraining the scope of this analysis to Eawag is intended to allow specific needs and demands with regard to KM to be clearly identified and characterized, not only for issues arising within Eawag but also issues that arise for Eawag as a member of the SWM community. This approach is intended to provide a basis for assessing measures to meet KM needs as well as barriers to KM that would need to be circumvented and, ideally, for proposing new approaches that could be pursued within Eawag or in cooperation with external partners.

1.1 The setting – Eawag’s funding, scope and mandate

Eawag is a publically-funded research institute that receives approximately 75% of its funding through direct support from the Swiss federal government. With this level of direct support, it is particularly incumbent upon Eawag to use its resources efficiently; effective KM is an integral aspect of efficient resource utilization.

The scope of Eawag’s activities is legally defined¹ and encompasses the following topics:

- Chemistry, physics, biology and microbiology of water.
- Ecology of aquatic systems.
- Drinking water and wastewater treatment technologies.
- Sustainable management of water supply and resources and of the water environment.

Eawag’s thematic scope focuses mainly on water quality, which reflects both the history of the organization (Eawag, 2011) and the abundance of water resources in Switzerland. Issues related to flooding are mainly addressed by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) though Eawag collaborates with WSL on projects dealing with aspects of flooding and flood protection that pertain to water quality and aquatic ecology.

Eawag is one of six institutions belonging to the Domain of the Swiss Federal Institutes of Technology (ETH Domain). These six institutions share a common mandate in research, education and expert consulting. Since Eawag does not grant degrees, it fulfills its mandate in tertiary education in cooperation with the Swiss Federal Institutes of Technology in Zurich (ETH Zurich) and Lausanne (EPFL), the Swiss Cantonal Universities and Universities of Applied Sciences, and also with international, degree-granting partners.

Eawag’s expert consulting in context of industrialized countries is mainly focused on Switzerland with further engagement in Europe resulting from common interests and projects. Many of Eawag’s applied projects in Switzerland are funded by the federal, cantonal and local authorities and are often conducted jointly with water and wastewater utilities. Eawag conducts expert consulting and research in low- and middle-income countries (LMICs) with support from the Swiss Agency for Development and Cooperation (SDC), the State Secretariat for Economic Affairs (SECO) and charitable foundations.

Because of its engagement with ETH Zurich, EPFL and the Swiss Cantonal Universities (which include joint professorial appointments), Eawag’s research benefits greatly from the participation of doctoral students as well as Masters and

¹<https://www.admin.ch/opc/de/classified-compilation/20032108/index.html> (in German).

Table 1.1 Eawag statistics (2016)

| | | |
|--|----|------------|
| Total staff (number) ^{a)} | | 472 |
| Scientific staff ^{b)} (number) | | 306 |
| with adjunct professorships | 12 | |
| with tenured or tenure-track appointments | 76 | |
| Joint professors ^{c)} (number) | | 17 |
| Supervised doctoral dissertations ^{d)} (number) | | 144 |
| Supervised Bachelor's and Master's theses (number) | | 136 |
| Base funding (CHF) | | 61,499,000 |
| External funding (CHF) | | 17,627,000 |
| Peer-reviewed (ISI) publications (number) | | 408 |
| Other (non-ISI) publications ^{e)} (number) | | 146 |

a) This number of staff corresponds to 422 FTE due to part-time appointments.

b) The scientific staff includes those doctoral students who are employed by Eawag.

c) With the exception of Eawag's Director, all joint professors are formally employed by the partner university.

d) This number includes dissertations by doctoral students who are Eawag employees as well as those who are directly supervised by an Eawag researcher and guest students spending >50% of their working time at Eawag.

e) This number corresponds to 74 non-ISI publications (which includes non-reviewed publications in trade journals) as well as 72 publications in the category of reports, books, book chapters and proceedings.

Source: Eawag Annual Report (<http://www.eawag.ch/en/aboutus/portrait/annual-report/>).

Bachelors students conducting projects and thesis research. The short residencies of students (especially as compared with Eawag's permanent scientific staff) poses specific challenges for KM. Summary statistics (for 2016) are presented in Table 1.1.

1.2 Understanding SWM-related demands for KM at Eawag

Eawag, as an organization with a focus on applied research, must manage a broad range of knowledge and information. Here the focus is on demands for KM that relate directly to SWM; knowledge management relating to organizational operation and performance is excluded.² In addition, SWM as an area of research shares many KM needs with other applied (and even fundamental) research areas. Some KM tools, structures and/or frameworks are generally applicable (i.e., to topics beyond SWM).

²Eawag reports operational statistics to the Board of the ETH Domain, which publishes summary statistics for all ETH Domain institutions in its Annual Reports (https://www.ethrat.ch/en/annualreport_2016).

An important aspect of SWM is that relevant knowledge includes not only technical knowledge (which derives mainly from the natural, social and engineering sciences) but also experiential and practical knowledge, which is often tacit (Tsoukas, 2011). SWM knowledge that derives from practical experience often develops during the interaction with stakeholders or practitioners in the context of applied projects or expert consulting. The tendency for such knowledge to remain as tacit, informal knowledge (which is held by individuals or, in the best cases, within networks) limits its wider application in SWM. An important challenge (but also opportunity) for Eawag is *how to articulate and access experiential and practical knowledge gained by its researchers through interactions with practice*.

Demands for SWM-related knowledge can also have different drivers. Internally-driven demands include the need for Eawag researchers to position proposed SWM projects and/or interpret the results of SWM projects in the context of previous relevant work. Analysis of gaps in existing SWM-related knowledge is generally needed as a justification for further research. Externally-driven demands arise from needs in engineering practice, water resources management and/or policy-making that may be linked with concrete projects or with formal or informal consultation. Externally-driven demands are often highly contextual, posing the challenge of *how to incorporate context adequately while still being able to identify and extract generalizable aspects*.

1.3 Current measures to meet SWM-related demands for KM at Eawag

Eawag's capacities for knowledge management have expanded over time, in concert with changing demands and opportunities. As related technologies (mainly in IT) develop, it is a constant challenge to decide on and make appropriate investments (including the decision to develop new capacities in house vs. out-sourcing). Perhaps even more challenging, though, is fostering new attitudes and norms regarding, for example, data management and data sharing to comply in a meaningful way with changing external expectations.

1.3.1 Data management

The rapidly-developing trend toward more systematic data management is a response to evolving norms in the scientific community (Fecher *et al.*, 2015; Soranno *et al.*, 2015), which in turn reflect both the expectations of the broader society for return on its investment in scientific research and the availability of tools for data management (Joseph, 2016). The fact that much scientific research is publically funded underlies growing requirements for measures ranging from

the specification of data availability to public data archiving (Kowalczyk and Shankar, 2011; Vines *et al.*, 2013).

Data Management Plans (DMPs) are increasingly required by funding agencies and DMP tools³ are being developed to support them. An accord for “Open Data in a Big Data World” has been endorsed by national scientific academies, scientific organizations, universities and research institutes (<http://www.science-international.org/>). Some publishers have adopted the Joint Data Archiving Policy (<http://datadryad.org/pages/jdap>) or comparable policies that require the publication-supporting data to be publicly available (Michener, 2015). This is also of direct interest to researchers because of the citation benefits associated with open data (Piwowar and Vision, 2013). However, the availability of reliable public repositories for data deposition varies widely among the scientific disciplines in which Eawag is engaged and the quality of deposited data is subject to criticism (Roche *et al.*, 2015). The Registry of Research Data Repositories, re3data.org (Pampel *et al.*, 2013), listed 1805 research data repositories when this chapter was written. Zenodo (<https://zenodo.org>) and Dryad (<https://datadryad.org>) are among the most used general-purpose repositories at Eawag. Options are increasing to publish data sets as products in journals such as Earth System Science Data or Scientific Data and to assign digital object identifiers (DOIs) to data sets (e.g., <https://www.datacite.org/>) or to publish single observations after peer review (<https://www.sciencematters.io/>) or “nanopublications” (Groth *et al.*, 2010).

Since 1972, Eawag has collaborated with the Swiss Federal Office of the Environment (FOEN) and the WSL in the National Long-term Surveillance of Swiss Rivers (NADUF) program. Through this program, standardized monitoring data on water quality are made available through the Eawag website (<http://www.eawag.ch/en/departement/wut/main-focus/chemistry-of-water-resources/naduf/>) to accompany hydrologic data available through the FOEN website. Note that other water data portals (i.e., websites with data or links to monitoring data on water resources including flow, water quality and integrated water resources management) (Hering, 2017) are an important resource for Eawag researchers.

Currently, a central research data (CRD) repository is being established at Eawag to provide intermediate- and long-term storage for datasets (Figure 1.1). This project is intended to support compliance with standards of good scientific practice for data retention and to enable the long-term archiving of unique, unrepeatable measurements. An additional anticipated benefit is increased collaboration within Eawag, including re-use of data that are discoverable through appropriate search queries. Data sets can be filtered by location, sampling periods, keywords and terms from several controlled vocabularies.

It is hoped that these ancillary benefits will help to motivate individual researchers to perform the organization, quality control and annotation of their

³Data Management Plan (DMP) Tool, Univ. of California (<https://dmp.cdlib.org/>); DMP Online, Digital Curation Centre (<https://dmponline.dcc.ac.uk/>).

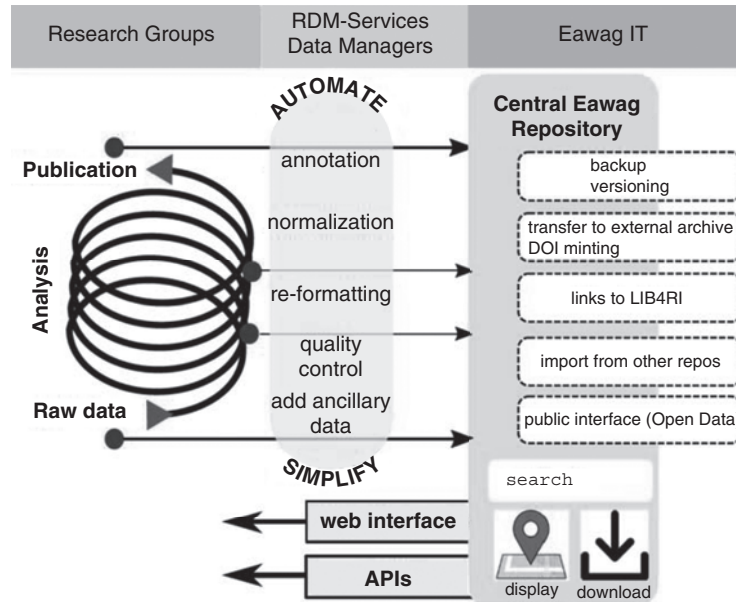


Figure 1.1 Schematic illustration of Eawag's research data management system. © Eawag. Used with permission.

data that is needed for a reliable research data repository. Additional activities related to the establishment of the repository include the provision of guidelines, training and ancillary tools and services to support researchers with their data-management and data-handling needs and thus to make usage as efficient and painless as possible.

Eawag's multidisciplinary environment (in which highly heterogeneous types of data are generated) necessitates substantial customization of its repository system. The open-source software CKAN (<http://ckan.org/>) was chosen largely because it is sufficiently modifiable to meet the broad spectrum of user requirements (Amorim *et al.*, 2015). Additionally, different groups require different ancillary tools to support the submission of data sets. For example, reliable uploading of large genomic datasets (10s to 100s of GB) requires a fully-featured command-line client script running on Linux (<https://github.com/eawag-rdm/resup#resup>), while conversion of proprietary file-formats to standardized ones is best served by MS Windows-based tools with a convenient graphical user interface (<https://github.com/eawag-rdm/sav2csv#sav2csv>). Eventually, a subset of Eawag's data will be made available through a publicly available server and tools will be provided to publish submitted datasets semi-automatically to external repositories such as Zenodo.

Data packages that are uploaded to Eawag's CRD repository are annotated with metadata. The design of the metadata-scheme is one of the project's central challenges. Consideration of metadata structure, extent, and implementation is

essential to assure the findability, accessibility and interoperability of data in the repository with the growing number of distributed digital collections (Park & Tosaka, 2010).

Metadata can be as simple as general-purpose vocabularies such as the DCMI Metadata Terms (DCMI, 2012) or the Data Catalog Vocabulary (DCAT) (W3C, 2014), which merely target semantic interoperability. In contrast, the highest level of metadata structure incorporates formally-specified ontologies that encapsulate domain-specific knowledge in a hierarchy of and relations among the terms of a vocabulary. Data annotated in this way can be used to derive new knowledge through automated reasoning as illustrated for water quality monitoring (Jajaga *et al.*, 2015).

The degree of complexity and completeness of metadata provisioning of Eawag's CRD repository is influenced by the effort needed to annotate the data, especially given the lack of available, appropriate domain-specific ontology. This effort must be balanced against the medium-time gains that can be realized through improved interoperability with other services and the necessity to establish a sustainable solution for the life-time of the repository.

In practice, general bibliographic metadata are represented according to the DataCite Metadata Schema (DataCite Metadata Working Group, 2016) which can be largely mapped to DCAT and DCMI Metadata Terms. This facilitates metadata exchange with DataCite and the DOI registration agency and can be handled by common metadata transmission standards such as OAI-PMH (Open Archives Initiative, 2015). In addition, a limited number of domain-specific metadata fields are used, which are drawn from existing vocabularies if possible (e.g. for lists of biological taxa). In the absence of existing vocabularies, specific controlled vocabularies are developed in collaboration with Eawag researchers.

Eawag has invested in support staff to meet these technical challenges as well as to provide information on archival standards, file formats, dataset submission guidelines and vocabularies for dataset classification, to co-produce software requirements and to consult on local data management practices.

1.3.2 *Management of scientific and technical knowledge*

The scientific literature provides an effective means of compiling formal scientific and technical knowledge from the natural, social and engineering sciences on all topics, including SWM. The scientific literature is well indexed and Eawag researchers have broad access to search tools (e.g., Web of Science, Scopus, etc.) as well as to journals and books through a library that is operated by Eawag on behalf of the four Research Institutes of the ETH Domain (<http://www.lib4ri.ch/>); the LIB4RI also offers trainings (particularly for doctoral students) on searching the scientific literature. Additional access to print materials (especially books) is provided through the Network of Libraries and Information Centers in Switzerland (<http://www.nebis.ch/eng/>). Eawag researchers also have access to bibliographic tools (e.g., EndNote). In this regard, KM for SWM poses essentially the same challenges as arise in other technical fields.

Scientific and technical conferences (usually organized through professional societies) also provide a venue for exchange of technical knowledge, usually in advance of journal publication. The tendency of individual researchers to align their networks within specific professional societies can lead to a lack of exchange across such societies. The accessibility of conference proceedings to society non-members (or even society members who did not attend a specific conference) can be highly variable. Technical knowledge presented at conferences can, however, be expected to be published (eventually) in the scientific literature.

Various organizations, both governmental and non-governmental, also issue reports containing SWM-related technical knowledge. Examples include water-related publications released by the OECD (Organization for Economic Cooperation and Development, <http://www.oecd.org/env/resources/water-publications.htm>), the World Bank (<http://www.worldbank.org/en/topic/water/research>) or UN Water (<http://www.unwater.org/publications>). Eawag produces only a limited number of self-published reports but does contribute to reports issued by Swiss Federal Offices, most commonly the FOEN (<http://www.bafu.admin.ch/?lang=en>). Some large projects, especially those funded by the European Union (EU), post comprehensive reports on project websites; relevant examples include: Sustainable Water management Improves Tomorrow's Cities' Health (<http://www.switchurbanwater.eu/>), Adaptive Strategies to Mitigate the Impacts of Climate Change on European Freshwater Ecosystems (<http://www.refresh.ucl.ac.uk/>), Transitions to the Urban Water Services of Tomorrow (<http://www.trust-i.net/index.php>). The Community Research and Development Information Service (CORDIS) provides a searchable index of EU projects (http://cordis.europa.eu/projects/home_en.html). While various reports can be found through search engines or through the websites of organizations and are almost always freely available, they are not reliably indexed and the process of finding them is often haphazard. Some organizations (including Eawag) issue newsletters and/or use social media outlets to provide entry points to technical information.

Eawag archives reports to which its staff has contributed (as well as all publications in the scientific literature by Eawag authors) in a structured, searchable institutional repository (<https://www.dora.lib4ri.ch/eawag/>). Full access to content is available within Eawag; external users can view metadata for all publications and can access content that is not restricted by agreements with external parties (e.g., publishers).

1.3.3 *Management of experiential and practical knowledge*

In contrast to technical knowledge, few (if any) standardized communication channels exist for experiential and practical knowledge. Such knowledge can include both practical intuition regarding complex technical systems that is derived from the experience of operating them and vernacular knowledge held by stakeholders involved in water resources management (Simpson *et al.*, 2015).

A further aspect of experiential knowledge, involving methods and practices of stakeholder engagement, transdisciplinary and/or action research, is partly systematized through the scientific literature (Jahn *et al.*, 2012; Klein, 2008; Pohl, 2008; Polk, 2015), though this is often fragmented in terms of specific applications (e.g., translational and public health medicine, development for LMICs, etc.).

One of the principal challenges of compiling experiential and practical knowledge is that it is often highly contextual and/or specific to a particular (technical) system. Such knowledge can be partly captured in case studies, which are often included in reports, technical guidance documents or other “gray literature”. A significant limitation to the further application and implementation of such knowledge, however, is the lack of a consistent and well-documented review process (quality control). In such cases, the reputation of the organization issuing the document is likely to influence the perception of its reliability. As with technical reports (described above), the lack of reliable indexing tends to result in haphazard access to this knowledge. Nonetheless, generalized searches can provide access to such material and visibility for content providers (including Eawag).

An important factor in documenting experiential knowledge is the involvement of social scientists in water management projects. Although the relevance of social sciences to water management has long been recognized (James, 1974), the recent trend of increasing cooperation among social scientists, natural scientists and engineers (which Eawag supports) has led to improved characterization of social networks and interactions, better incorporation of vernacular knowledge and more reflection on processes of integration and stakeholder engagement (Butterworth *et al.*, 2011; Hoffmann *et al.*, 2017a; Hoffmann *et al.*, 2017b; Simpson *et al.*, 2015). Without integration of the social sciences, the experience of participants in water management projects (including social learning) is likely to be held only by individuals or within networks and documented only in unsystematic records such as agendas and minutes of public meetings (though these can potentially be analyzed post hoc). Eawag is supporting a Community of Practice (CoP) for individuals employed by or affiliated with Eawag who are working at the interface of science and practice. Such a CoP, composed of individuals who share expertise and experience in a specific domain of activity (Wenger & Snyder, 2000), can facilitate the exchange of experiential knowledge within the network. It remains a challenge to make this knowledge more generally accessible.

1.4 Unresolved issues and challenges in SWM-related KM

Although Eawag’s experience is certainly not unique, it provides insight into the unresolved issues and challenges related to KM, generally, and to KM for SWM in particular.

1.4.1 *Information overload and fatigue*

The availability (or over-availability) of information is generally perceived in the context of prior experience and/or technological innovation, making information overload a nearly timeless phenomenon. In the current context of scientific and technical KM, the overall number of records in the Core Collection of the Web of Science is estimated to be growing by about 2–3% per year (Larsen and von Ins, 2010) with estimated growth exceeding 10% per year in the field of water management (Ren *et al.*, 2013).

Associated with information overload (Eppler & Mengis, 2004) and the accompanying information fatigue are a number of coping strategies (Landhuis, 2016). For scientific and technical knowledge, these may include: over-reliance on metrics (e.g., journal impact factors or citation rates) as proxies for quality, idiosyncratic search strategies with semi-arbitrary criteria for search termination, under-use of less easily accessible information sources such as (printed) books and reliance on recommendations from personal contacts or recommender systems (Beel *et al.*, 2016).

1.4.2 *Open access*

The debate over open access is proceeding in a rapidly-evolving context. Publishers are coming under increasing pressure to develop business models for open access that are economically viable for authors and libraries (LERU, 2015). In late 2016, a German library consortium failed to come to an agreement with the publisher Elsevier; open access and cost were the major points of contention (Vogel, 2016). In the absence of (or in parallel to) library subscriptions, researchers are likely to rely more heavily on sites such as Google (Scholar) (<https://scholar.google.com>), Research Gate (<https://www.researchgate.net/>), Academia (<https://www.academia.edu/>) or Sci-Hub (<http://sci-hub.io/>), without regard to the questionable legal status of documents deposited on (or accessible through) such sites. Preprint servers, mainly arXiv (<https://arxiv.org/>) and bioRxiv (<http://biorxiv.org/>), are being increasingly used by Eawag researchers, not only to provide open access but also to establish (early) claims to intellectual property. Issues relating to copyright, however, remain murky and publishers have differing policies regarding whether preprints are considered as prior publication (Lawal, 2002).

Eawag does not have formal requirements for open access publication but provides financial support for “gold road” open access publication (though not for “hybrid” open access). “Hybrid” open access, particularly its vulnerability to “double-dipping” by publishers, has been a key issue in arguments with publishers. Eawag also strongly encourages “green road” open access publication of post-prints (<http://www.lib4ri.ch/services/open-access.html>), which makes content available to readers without institutional access to subscribed content. “Green road” open access, however, depends on authors to deliver post-prints

to the repository and is, in some cases, blocked by publishers for an embargo period (which is often one to two years). These may be factors in the continuing attractiveness of “hybrid” open access to researchers in environmental science and engineering since many leading journals in this field are not “gold road” open access.

1.4.3 *Quality control and collaborative editing*

The proliferation of open access journals has highlighted the issue of quality control in the conventional peer review process, which was exposed in an investigation by the journal *Science* (Bohannon, 2013). These concerns are not limited to open access journals, as illustrated by increases in retractions (Steen *et al.*, 2013). Forums for post-publication review are provided by Faculty of 1000 (F1000, <http://f1000.com/>), which focuses on biology and medicine, and PubPeer (<https://pubpeer.com/>). F1000 has expanded its service to include an open publishing platform that offers immediate publication and transparent peer review. This model has been adopted by major funders including the Wellcome Trust (<https://wellcomeopenresearch.org/>) and the Bill and Melinda Gates Foundation (<https://gatesopenresearch.org/>). An open review process is conducted by Copernicus Publication, which provides platforms that host unsolicited public comments in parallel to reviews solicited by an editor (http://publications.copernicus.org/services/public_peer_review.html). The trend toward open and continuous peer review, in which scientific reports are considered as “living documents” (Shanahan, 2015), has the advantage of corresponding to the actual development of scientific understanding. At the same time, it poses challenges to attribution and quality control as implemented in conventional scientific publishing and peer review.

Eawag’s current practices rely heavily on (external) peer review, particularly since there is no institutional requirement for internal review of papers that are submitted to peer-reviewed journals. Publication in leading peer-reviewed journals is also an important criterion for decisions on staff advancement (e.g., tenure and promotion).

More generally, there is an implicit assumption of the quality of peer-review in the growing trend toward (comprehensive) systematic reviews, which have been promoted as an antidote to individual bias (Bilotta *et al.*, 2014; Cvitanovic *et al.*, 2015; Spruijt *et al.*, 2014). This trend runs counter to the past expectation that critical reviews would provide filtering of the available material based on the expert judgment of the author(s) (Nilsen, 2015).

The issue of quality control in the peer-reviewed technical literature is even more acute for reports released by project consortia and/or institutions that are subject to varying (and often unstated) levels of review. The pressure for inclusiveness (which is often an explicit requirement of large programs funded by the EU) is not always compatible with discerning quality control. This places an even

greater burden on the researcher (or other readers) who might rely on information in the gray literature.

1.4.4 Resource demands

Quality control clearly demands resources (i.e., the time and attention) of researchers. Indeed, many failings of the peer review system are attributed to the increasing and competing demands on researchers' time. Appropriate curation and archiving of knowledge (including but not limited to data) are also activities that demand both time and expertise. Even updating of websites that function as knowledge portals takes time – often there is no obvious indication when specific websites are no longer actively maintained.

Needed resources can be provided by institutions or funding agencies (Hering, 2015). When they are not, dangers arise that knowledge platforms will take on an unacknowledged promotional character (serving the self-interest of contributors) and/or that paywalls will be constructed that limit access to knowledge (Hering & Vairavamoorthy, 2017).

1.5 Future directions for SWM-related KM

Eawag attempts, through various measures, to support its researchers in effectively accessing and contributing to the knowledge base for SWM. Some of the challenges and obstacles to this, however, call not only for new tools but also for changes in attitudes and expectations within the SWM research community. As a leading research institute in this field, Eawag can hope to have some influence on these norms and attitudes.

The deluge of scientific and technical literature (including that related to SWM) has been linked with trends in metrics and incentives in academics and funding agencies (Benedictus *et al.*, 2016; Hammarfelt *et al.*, 2016). In addition, bibliometric indicators have been criticized as having an inhibitory effect on inter- and transdisciplinary research (Zilahy *et al.*, 2009), which is clearly an issue for SWM. Eawag attempts to provide recognition for publications that are directed toward non-academic audiences (e.g., appearing in trade journals) and, for academic publications, to emphasize quality over quantity. It is, however, open to debate whether quantity (as opposed or in addition to quality) affects impact; an effect of quantity was reported in a recent study in which impact was assessed on the basis of citations in the Web of Science within 3–6 years of publication (Sandstrom & van den Besselaar, 2016). Nonetheless, Eawag supports the view that a shift to focusing on content, with the understanding that metrics are (at best) surrogates, and attention to impact outside academia are needed (Benedictus *et al.*, 2016).

A change in attitudes at various levels is also needed to combat “platform proliferation syndrome”, which reflects the “allure of setting up new initiatives, rather than building on what’s already there” (Barnard, 2013). A key issue is the need to adopt common standards and open data principles, which would also eventually support data mining and machine learning (i.e., the semantic web). This approach is being fostered in the development (<https://www.okhub.org/>) and climate adaptation (<https://www.weadapt.org/>) communities. The issues of attribution and quality control also need to be addressed in this context. Eawag would be interested in working with other organizations to develop such models for SWM-related knowledge and welcomes input to the Open Science Framework project “Freshwater Knowledge Hub” (<https://osf.io/28rhn/>).

The lack of accessibility of publications and technical content (e.g., located behind paywalls of publishers or professional societies) is a major impediment to text mining (Peters *et al.*, 2014; Shemilt *et al.*, 2014). Text and data-mining (TDM) for non-commercial research purposes is explicitly allowed under UK copyright law if the researcher has lawful access (i.e., through a subscription or license) to the material (<https://www.jisc.ac.uk/guides/text-and-data-mining-copyright-exception>). Collections of open access papers (e.g., <https://www.scienceopen.com/>) offer a substantial advantage for TDM but this is, of course, limited to the papers in the collection. Other repositories (e.g., PubMed Central) allow papers to be downloaded and read individually, but connection to natural language processing tools needed for effective TDM is limited to the open access subset of the collection (Doring *et al.*, 2016).

The useful application of machine learning to the pharmaceutical patent literature (which has the advantage of being publically accessible) has been demonstrated (Schneider *et al.*, 2016). This approach could be extremely useful in SWM, but the SWM community would need to coordinate efforts to make this possible.

1.6 Concluding comments

With the SDGs (particularly Goal 6), the SWM community faces both enormous challenges and exciting opportunities. Simply collecting and compiling the monitoring data on indicators to support SDG 6 is a significant task being coordinated through several agencies of the United Nations (UN Water, 2016). Actually achieving the targets under SDG 6, particularly by 2030, will require that existing knowledge is marshaled and used to implement solutions (Hering *et al.*, 2016; SDSN, 2015). Improving knowledge management is an essential component of this task.

The knowledge management issues faced by the SWM community reflect more general issues relating to the overwhelming abundance of scientific and technical knowledge. The SWM community would do well to endorse and

support the 12 Vienna Principles – accessibility, discoverability, reusability, reproducibility, transparency, understandability, collaboration, quality assurance, evaluation, validated progress, innovation and public good (<http://viennaprinciples.org/>) – or the “fair principles” that also address machine learning (<https://www.force11.org/fairprinciples>).

In this context, Eawag serves as a microcosm illustrating current practices, challenges and outlooks for SWM-related KM. Eawag’s perspective is that of a research institute (i.e., mainly a knowledge provider). Knowledge production, however, also entails the discovery and integration of existing knowledge. Furthermore, it is in the interest of all knowledge providers that the knowledge produced is accessible for implementation and as the basis for further research. No single institution can overcome the barriers to the effective sharing and utilization of knowledge, but together, institutions engaged in SWM can hope to move the SWM-community in this direction.

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