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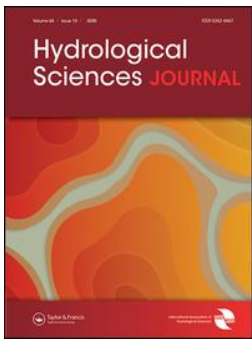
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Intergovernmental cooperation for hydrometry – what, why and how?

Harry Dixon^a, Sophia Sandström^b, Christophe Cudennec^c, Harry F. Lins^d, Tommaso Abrate^b, Dominique Bérod^b, Igor Chernov^b, Nirina Ravalitera^b, Daniel Sighomnou^b and Florian Teichert^b

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ABSTRACT

Two thirds of hydrological observation networks in developing countries are reported to be in poor or declining condition. At the same time innovation in sensor technologies and data processing are presenting opportunities for enhancing observation networks that are not being realized. The World Meteorological Organization's Global Hydrometry Support Facility, or WMO HydroHub, was launched in 2016 to transform assistance to operational water monitoring agencies around the world. If successful, the initiative will increase the amount of hydrometric data available to researchers, catchment managers and water policy makers. To those unfamiliar with UN organizations, however, the nature of such initiatives, the reasoning behind the decisions taken to establish them and the mechanisms by which they try to deliver benefits for society, can be opaque. This paper adopts a novel dialogue-style format to explore the set-up of the WMO HydroHub and build awareness amongst those who ultimately may benefit from its approaches.

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Introduction

The dawn of the 21st century has been marked by water assuming an unprecedented position in global environmental and political agendas. This was initially reflected in the framework of the Millennium Development Goal, where Target 7 C aimed to “*Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation*” (UN 2000). More latterly, the global focus on water issues has been broadened through a dedicated goal on Water in the framework of the 2030 Agenda for Sustainable Development: Sustainable Development Goal (SDG) 6 “*Ensure availability and sustainable management of water and sanitation for all*” (UN 2015). Water also plays an important role in many other SDGs (UN Water 2016) and, reflecting its widespread importance, recent years have seen the emergence of committed international leadership panels aimed at moving the water agenda forward (e.g. High Level Panel on Water 2018). As a result of these unrelenting global initiatives at all levels, 2.6 billion people have gained access to an improved drinking water source since 1990 (WHO 2015). Many challenges remain however if we are to meet the water-related needs and rights of an increasing global population (WWAP 2019, UN Water 2019a)

Today's world is undergoing significant acceleration in environmental, political, economic and social change and development, resulting in deep transformations across various sectors of society (Bai *et al.* 2016, Brondizio *et al.* 2016). New rapidly emerging trends are disrupting ‘business as usual’ approaches and mind-sets. These trends are characterized by complex conditions encompassing elements of volatility, uncertainty, complexity and ambiguity making it challenging

to craft appropriate responses (George 2017). What are the effects of climate change on migration and peace? What impact will developments in artificial intelligence have on societies? How can we discern accurate news and information from the overflow of erroneous headlines disseminated through traditional and social media? The understanding and interpretation of such changes are becoming more and more intangible and intertwined.

This is also the case for the management of the world's freshwater resources and the risk posed by hydrological extremes (McMillan *et al.* 2016, Di Baldassarre *et al.* 2019, Blöschl *et al.* 2019). A changing climate is impacting upon water availability and competing demands on water resources are leading to acute pressures in many catchments (Ceola *et al.* 2016, UN Water 2019a). Globally, flooding affects 250 million people and causes 40 billion USD in losses on an annual basis (OECD 2016). Not surprisingly, the water crisis ranks fourth global risk in terms of impact in the 2019 Global Risks Report (WEF 2019). Yet in spite of this, many areas of the world continue to lack the vital data needed to develop the hydrological information products and services needed to combat these risks. Sustainable management of catchments is reliant on rigorous water resources assessments (Lins 2008), yet operational agencies often suffer from a shortage of sound and reliable observational data needed to underpin these. Indeed, an assessment of the state of hydrological services in developing countries published by the World Bank in 2018 reveals that two thirds of their observation networks are reported to be in poor or declining condition (World Bank 2018).

Within the research sector, the pursuit of new knowledge to further our understanding of hydrological systems and inform

tomorrow's management practices is often hampered by a scarcity of data (Viglione *et al.* 2010, Hannah *et al.* 2011, Blume *et al.* 2017, Blöschl *et al.* 2019). Conversely however, an increasing number of technological innovations are emerging from academia/research and the private sector, as well as from citizen engagement, which have the potential to provide new and improved observational data, yet take-up within operational hydrological monitoring is low (Tauro *et al.* 2018, World Bank 2019).

In the light of the challenges facing the global population, many are now asking how this lack of global monitoring capacity, limited assimilation of innovations into mainstream hydrological monitoring networks, and the limited accessibility to existing data can be tolerated.

The World Meteorological Organization (WMO¹) is an intergovernmental organization that supports National Meteorological and Hydrological Services (NMHSs) in overcoming such barriers through a diverse range of mechanisms and initiatives. Hydrological Services is a term which is often used to cover institutions who provide information about the water (or hydrological) cycle, typically including the assessments of water resources status and provision of flood forecasts (World Bank 2018). The institutional form of NMHSs varies from country to country depending on national legislations and the role of the private sector. In the case of hydrology, Services may be joined with those for delivering meteorological information (often known as Hydrometeorological Services), be part of bodies delivering other related public tasks (such environmental protection and regulation) or, in many cases, exist as separate agencies focusing on operational hydrology. Furthermore, it is also common for there not to be a single National Hydrological Service for a country, with such functions being delivered by multiple organizations, divided along geographical or technical boundaries (WMO 2006).

Over the last 60 years, WMO has evolved a series of mechanisms by which it supports this complex network of Hydrological Services (Lins 2010). These routes of support include the development of standards,² delivery of education and training,³ promotion of good practices and support in the implementation of projects.

One particular area of focus for WMO has been supporting Hydrological Services in the area of data collection and management. This support for hydrometry, which the WMO and UNESCO define as “*Science of the measurement and analysis of the water cycle including methods, techniques and instrumentation used in hydrology*” (WMO and UNESCO 2012, p. 173) underpins many other areas of operational hydrology. In 2016, to strengthen its activities in this field, WMO launched the WMO Global Hydrometry Support Facility (known as the WMO HydroHub⁴) which aims to transform the assistance the Organization provides to water monitoring around the world, bringing together a range of activities and reaching out to new stakeholders.

The technical breadth of WMO's support and constant development of technologies and approaches has resulted in a broad range of ongoing activities and significant body of printed and digital outputs.⁵ For those working within NMHSs, WMO engagement is often key to delivery of their roles and as a result, knowledge of its methods of working and signposts to the more appropriate resources are commonplace. For those outside the immediate ‘WMO Community’, however, awareness of how such an intergovernmental organization supports its Members and the tools it provides to society at large is sometimes less widespread. The mass of technical literature and network of interconnected initiatives can at first sight appear indecipherable. An example of this can be seen in the hydrological research community, many of whom rely heavily on the data produced by NMHSs to advance scientific knowledge, which in turn helps further develop operational services. Despite this symbiotic relationship, knowledge of WMO's work to support hydrometric monitoring is piecemeal.

The interdisciplinary nature of water means that no one sector of society, or single organization, can meet the monitoring challenges we face. Within the UN system alone, there are multiple organizations and bodies working in the field of water (UN Water 2019b). Curating knowledge about WMO's activities and the key corresponding resources in a broadly accessible manner should therefore provide strong added value and multiplying effect – enabling others to benefit from and contribute to the common cause. Such an approach aims to facilitate greater awareness and capacity development of individuals as well as groups and ultimately institutions, in the same ways as curation-based education, training and popular science do in the current epoch of informational tsunamis. This paper aims at providing such a curation and perspective in relation to WMO's efforts to build hydrometric capacity and innovation around the globe.

To do so, this paper adopts a dialogue-style format whereby extracts from the WMO HydroHub's Strategic Plan (shown in text boxes throughout the paper) are considered by means of questions and answers. The questions are posed from the perspective of those outside the ‘WMO Community’ and, as such, the format is designed to offer a reflexive entry point for any reader to the topics addressed and the detailed resources referred to. This is similar to flipped classrooms, which catalyse capacity development and metacognition with hybrid audiences, often displaying to-be-consolidated and accompanied knowledge, skills, intuitions and ambitions. Such a format has proven to be efficient since Antiquity, especially with Plato's dialogues. It is efficient in terms of flexibility, adaptability, problem solving and innovation at the individual (mind-set, job), organizational and societal levels in a changing world (WWAP 2016). Publishing in *Hydrological Sciences Journal* aims to bridge a diverse community of readers including academia, students, practitioners, enlightened citizens and policy makers.

¹www.wmo.int.

²<https://tinyurl.com/sttxrbz>.

³<https://tinyurl.com/t9gnydj>.

⁴<https://hydrohub.wmo.int>.

⁵<https://library.wmo.int/>.

Intergovernmental support for water monitoring

Extract from the WMO HydroHub Strategic Plan:

"The World Meteorological Organization (WMO) supports the whole value chain of hydrological products and information from water monitoring to warnings and outlooks."
(WMO 2018b, p. 3)

Question: What is WMO's role in operational hydrology?

The WMO has operational hydrology in its portfolio but is not an operational entity itself. This question is therefore intended to help the reader understand WMO's mandate in relation to helping those organizations who do conduct operational monitoring in their efforts to meet the growing demands on hydrological data around the world.

Response: Supporting its Members and their national services

The WMO is a specialized agency of the United Nations (UN) with 193 Member States and Territories. WMO acts as a central framework where Members can effectively discuss issues related to weather, climate and water. Through this process, WMO helps Members' NMHSs and others deliver vital information services to society more widely – including, weather forecasts, hazards risk quantification and climate indicators. In addition to activities taking place in Member States and Territories, WMO has a Secretariat based in Geneva which acts as an administration, documentation and information centre for the Organization.

Specifically on water, and as outlined in the WMO Convention (WMO 2019a), the purpose is to promote activities in operational hydrology and to further close cooperation between Meteorological and Hydrological Services. In doing so, WMO helps support the full hydrological data value chain – from initial data acquisition, through the development and delivery of products and services, to the resulting knowledge sharing. This includes assisting its Members in operational hydrology matters that span observations, data processing, analysis, forecasting and warning. It does this through fostering cooperation, coordination, innovation, research and capacity development within the 'WMO Community' of NMHSs and related organizations.

Extract from the WMO HydroHub Strategic Plan:

"Mission

To help expand a reliable and sustainable base of hydrometeorological data and information services in support of informed decision and policy-making in water management.

Objectives

- (1) *Enhance and sustain efficient and innovative hydrological monitoring systems around the world.*
- (2) *Foster the use of hydrometeorological data for evidence-based policy and decision-making in support of Integrated Water Resources Management and Disaster Risk Reduction, especially in transboundary settings.*
- (3) *Facilitate the modernization and improvement of operational hydrology through operational uptake of innovative hydro-metric technologies and services by National Meteorological and Hydrological Services."*

(WMO 2018b, p. 5)

Question: How is WMO increasing its support for water monitoring?

The requirement for improved freshwater monitoring is well established and the WMO has been offering support to Hydrological Services for over 50 years. To place the activities outlined in the rest of this paper in context, this question is intended to help the reader understand what is changing in the way WMO supports hydrometry and what the long-term objectives of the new developments are.

Response: A global focal point for hydrometry

The WMO HydroHub was established to enhance water monitoring systems in the world by bringing a broad range of stakeholders from different sectors together and providing them with sustainable technical guidance and support. The aim was to change the global agenda around hydrological data and information, raising the profile of water monitoring activities by demonstrating why investments are needed and improving the way that hydrometric observation networks are built and operated.

Three main objectives for the WMO HydroHub were identified: the first focuses on sustainable maintenance and expansion of observation networks for hydrology; the second on ensuring that the data flows from these networks to those who need it; and the third on opportunities which could allow services to be delivered in new ways.

Recognizing that the WMO already had a number of ongoing activities around hydrological data collection and exchange which have been developed over many years in response to countries' needs, the WMO HydroHub was designed to leverage existing WMO expertise and programmes, supplementing these where needed with new mechanisms designed to reinforcing the capability of WMO Members to collect and manage data – the end goal being to increase the base of hydrometric data and information available to end-users from various economic sectors.

This is being done by providing a framework within which sustainable capacity development projects can be implemented; furthering the technical standards, tools and mechanisms Hydrological Services use to collaborate; and establishing a hydrometric support ecosystem based on peer-to-peer support. Across all, user-driven activities which embrace new approaches while also maintaining high quality service provision are being supported.

Although supporting NMHSs is a key focus of the WMO HydroHub, it is important to highlight the important role that stakeholders from all sectors (public, private, academic and wider society) play in improving global water monitoring. The recently adopted Geneva Declaration – 2019: Building Community for Weather, Climate and Water Actions (Resolution 80) – by WMO's supreme decision-making body, the WMO Congress, reflects the need for a collective response to global societal risks related to extreme weather, climate change, water scarcity and other environmental hazards (WMO 2019b). Building such multi-stakeholder partnerships

is an important requirement of a number of areas of the WMO HydroHub's work, including the promotion of innovation in monitoring and the promotion of greater data sharing.

Setting up a new global initiative

Extract from the WMO HydroHub Strategic Plan:

"... the WMO established the Global Hydrometry Support Facility (WMO HydroHub) to enhance support for hydrological monitoring by National Meteorological and Hydrological Services (NMHSs) around the world and capitalize on the numerous opportunities arising from recent developments in innovation research and data/information technology."
(WMO 2018b, p. 3)

Question: What were the first steps in setting up the WMO HydroHub?

The establishment of new initiatives within intergovernmental organizations such as WMO can take time, often requiring a number of decisions by different bodies and support from around the world. This question is designed to help readers understand in what context was it decided to establish a support facility for hydrometry, and how the WMO HydroHub is set up and governed.

Response: To bring together existing and new initiatives and build support for a new mode of operation through intergovernmental decisions, strategic planning and new governance

Intergovernmental decisions

In 2014, the WMO proposed to establish a Global Innovation Hub, as a way of strengthening its hydrometry mandate. This proposal was driven by a recognition that advances in low-cost open-innovation sensor and communication technology, hard and software integration, and data synthesis, provided new opportunities in the form of non-traditional, person-centred mobile sensing for increasing data coverage; effective data management and secure data exchange; as well as the production of knowledge for effective and sustainable resource management. A year later, the WMO Congress endorsed the establishment of the Global Innovation Hub to promote large-scale uptake of innovation technologies.

In parallel to the innovation discussions, a full review of the World Hydrological Cycle Observing System (WHYCOS) was being concluded. WHYCOS, which is discussed in detail later, was a long-standing initiative designed to strengthen basin-wide and regional cooperation in relation to basic hydrological observation and data exchange. The review recommended that a specific office be set up within the WMO Secretariat to support the management and sustainability of the programme in a new way.

Discussions on the side-line of the WMO Congress explored bringing the Global Innovation Hub and the recommended WHYCOS office under a single operational support structure. One year later, with financial support from the Swiss Agency for Development and Cooperation (SDC), WMO established the WMO HydroHub to enhance support for hydrological monitoring by NMHSs around the world and capitalize on the numerous opportunities arising from recent developments in innovation research and data/information technology (Sandström and Steiner 2017). The structure and governance of the WMO HydroHub are schematized in Fig. 1.

Governance

As is commonplace with initiatives which have a broad stakeholder community, two governance bodies, namely the Advisory Council (AC) and the Innovation Committee (IC) were established for the WMO HydroHub. Strategic guidance is provided by the AC, whose memberships comprises experts covering various aspects of the disciplines and a broad range of organizations (UN organizations, private sector, donors, national services) in a way that ensures engagement from key stakeholders. The AC is chaired by a WMO expert designated by the relevant WMO constituent body.

The IC, a subsidiary body to the AC, comprises members with specialist interests in new methods of monitoring and technological development. It drives innovation in the work of the WMO HydroHub through reviewing its Innovation Strategy.

Strategic planning

Once the decision to establish the new initiative had been taken and governance arrangements put in place, focus shifted to more detailed planning of the WMO HydroHub. In the first years of its establishment, the WMO HydroHub prepared some key strategic documents to help organize the thinking on various aspects of the initiative and articulate plans to move forward, towards achieving its main goals. All of these strategic documents are interlinked, complement each other, and are regularly adjusted along the project lifetime.

The main strategic documents developed include:

- A Strategic Plan 2018–2020 (WMO 2018b) which outlines the general objectives, strategic priority areas and indicators for success within the timeframe.
- A Resource Mobilization Strategy, outlining the fundraising goals beyond the initial support provided by SDC and the methodology in which they will be achieved.
- An Innovation Strategy (WMO 2018a), which provides a definition of innovation in the context of hydrometry, and outlines key areas where new developments could be encouraged.
- A Communication Strategy, encapsulating the way communication channels and material will support the project to reach its goals.

Some of these strategic documents are available to the broad hydrometry community and beyond⁶ and help inform

⁶<https://tinyurl.com/s47vyof>.

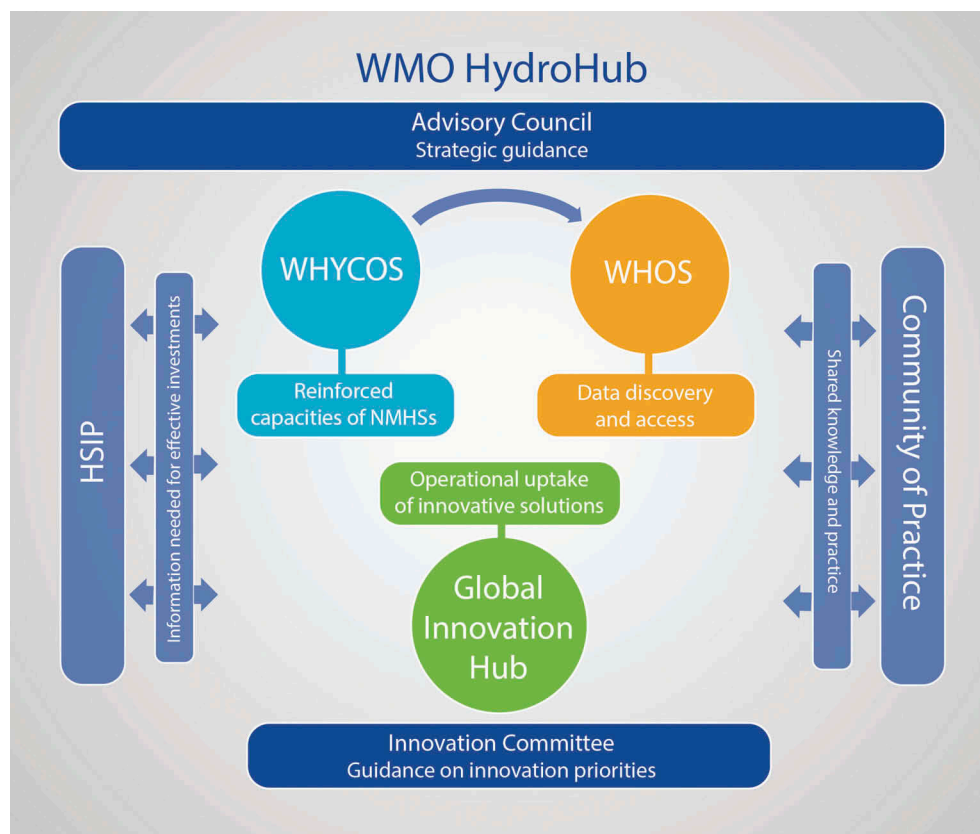


Figure 1. WMO HydroHub structure and governance.

interested stakeholders on various ongoing and planned activities. Extracts from the first of these documents, the WMO HydroHub Strategic Plan (WMO 2018b), form the focus of this paper.

Components of the WMO Hydrohub

Extract from the WMO HydroHub Strategic Plan:

"The Global Hydrometry Support Facility makes the portfolio of expertise among WMO Members – from science to technology to services – available to support access to end users of hydrometeorological data and services from various economic sectors as tailored services. These connections help to increase the base of hydrometeorological data – catalyzed by innovative technologies and approaches – to support WMO Members in water-related decision-making."

(WMO 2018b, p. 6)

Question: How is WMO structuring its support for hydrometry?

The WMO HydroHub has been established by bringing together different existing initiatives with some new activities. It is important to understand how these elements complement each other to provide an integrated package of support for hydrometry.

Response: Through a series of interlinked components targeting different aspects of the water monitoring problem

The WMO HydroHub is structured around five components with the overall mission to help expand a reliable and sustainable base of hydrometric data and information services in support of informed decision- and policy-making in water management. The five components of the WMO HydroHub are detailed below:

- Hydrological Services Information Platform (HSIP⁷), providing up-to-date information needed for effective hydrometric investments, including information on organizational, human and technical capacities of NMHSs and other relevant organizations as well as information on past and ongoing hydrometric capacity development activities in the country.
- World Hydrological Cycle Observing System (WHYCOS⁸), aiming at building and reinforcing the technical and human capabilities of NMHSs to perform their basic role in measurement network design, data collection and management and information production and dissemination, and to promote regional and basin-wide cooperation in hydrology.
- Global Innovation Hub,⁹ facilitating the uptake by NMHSs of new water monitoring approaches, from devices to management, including data transmission systems. Reducing overall costs (for example through self-

⁷<https://hydrohub.wmo.int/en/hydrological-services-information-platform>.

⁸<https://hydrohub.wmo.int/en/world-hydrological-cycle-observing-system-whykos>.

⁹<https://hydrohub.wmo.int/en/global-innovation-hub>.

manufacture of devices in developing countries based on open licenses) and increasing effectivity of water monitoring are at the core of the innovation efforts.

- WMO Hydrological Observing System (WHOS¹⁰), enabling hydrological data registration, discovery and access based on a brokering approach and a standard sharing formats. WHOS is being developed as the hydrological component the WMO Integrated Global Observing System (WIGOS¹¹), the overarching framework which is being implemented to coordinate and optimise existing meteorological and related environmental observation systems.
- Community of Practice (CoP¹²), facilitating mutual support and better peer-to-peer connections between hydrometric practitioners around the world and learning opportunities that are based on shared practices to tackle day-to-day operational challenges faced by NMHSs, including those related to new practices and technologies.

The WMO HydroHub operates in a way that interlinks each of its components. The HSIP provides the baseline information about current global hydrometric monitoring, based on which the WMO HydroHub will: provide targeted support to enhance observation networks (through WHYCOS); modernize the approaches used to do so (through the Global Innovation Hub); and facilitate peer-to-peer support to sustaining improvements into the future (through the CoP). The end point of these efforts is metadata and time series data, which are then shared with stakeholders through WHOS as an input to information services developed through other programmes.

The WMO HydroHub also aims to align with broader strategies within WMO, with a view to providing integrated support from data to decisions. For example, the WMO HydroHub is closely associated with the WMO Hydrological Status and Outlook System (HydroSOS), a recent initiative aiming at providing globally consistent information on current hydrological conditions and how they are likely to change over coming months. The enhanced monitoring and data management capabilities of NMHSs which the WMO HydroHub activities will bring about aim to underpin HydroSOS. The increased reliability of long-term hydrological monitoring networks provided by WHYCOS, improved data exchange technologies in the form of WHOS and new observations from the Innovation Hub are all going to be critical in providing the information based needed for HydroSOS.

In addition to close interactions between the different components of the WMO HydroHub and with other WMO activities, in setting up the Hub, consideration had to be given to priority linkages at a broader scale. Engagement with the hydrological projects and ventures of development partners, such as the World

Bank, Agence Française de Développement (AFD) is key, with such organizations contributing to the Governance of the WMO HydroHub to ensure it delivers benefits aligned with their efforts. It is currently anticipated that, when fully operational, the WMO HydroHub will also support enterprises such as: implementation of the Green Climate Fund (GCF¹³) projects; development of the Global Framework for Climate Services (GFCS¹⁴); and will help WMO Members contribute to efforts such as the World Water Quality Alliance led by UNEP.

As well as proactively engaging with those development partner organizations involved in supporting hydrometric capacity development projects around the world, the WMO HydroHub has sought to involve bodies such as the International Association of Hydrological Sciences¹⁵ in order to ensure a link with the latest developments in the hydrological sciences. Other UN bodies with interests in hydrometry, such as the UNESCO Intergovernmental Hydrological Programme (IHP) and the Food and Agriculture Organization (FAO), are engaged as partners. Key linkages with the private sector are fostered through organizations such as the Association of Hydro-Meteorological Equipment Industry.¹⁶

Understanding the current state of monitoring networks

Extract from the WMO HydroHub Strategic Plan:

“current information on governmental and non-governmental water monitoring organizations, and their capabilities, structure and network and data sharing characteristics.”

(WMO 2018b, p. 6)

Question: How will the WMO HydroHub collate information on current operational hydrometry?

Concerns about declining hydrometry networks are widespread however an up-to-date overview of on current capabilities and needs within the operational hydrology community can be difficult to obtain.

Response: development of a hydrological services information platform

In low- and middle-income countries, an important barrier to satisfying the increasing demand for reliable and accessible hydrological data, is the unsustainability and ineffectiveness of international investments and technical assistance programme designed to strengthen Hydrological Services (World Bank 2018). To overcome this, it is critical that

¹⁰<https://hydrohub.wmo.int/en/whos>.

¹¹<https://public.wmo.int/en/programmes/wigos>.

¹²<https://hydrohub.wmo.int/en/community-practice-hydrometry>.

¹³www.greenclimate.fund.

¹⁴gfcs.wmo.int.

¹⁵<https://iahs.info/>.

¹⁶<https://www.hmei.org/>.

potential funders and development partners have an open access to information on governmental and non-governmental water monitoring organizations, and their capabilities, structure and network- and data-sharing characteristics.

To help meet this challenge, the WMO HydroHub is developing the Hydrological Services Information Platform (HSIP), which will freely and openly display up-to-date monitoring information essential for effective hydrometric investments. This information will be sourced via in-depth organizational and technical assessments of NMHSs and relevant water resources management and hydrological forecasting agencies, including Basin Organizations worldwide. To keep the HSIP information up to date, a WMO Hydrology Online Survey will be conducted across NMHSs and other related organizations of WMO member countries on an annual basis, the responses to which will be analysed and used help inform development partners regarding pressing global and national needs.

Building hydrological monitoring capacity

Extract from the WMO HydroHub Strategic Plan:

“Goal

The Global Hydrometry Support Facility provides an efficient, innovative and sustainable framework to support operational systems in hydrometry and water monitoring of national hydromet services.

Expected Result 1

The Global Hydrometry Support Facility modernizes the WHYCOS framework to increase ownership, sustainability and upscaling.”

(WMO 2018b, p. 7)

Question: Why do we need to modernise the way we help build hydrological monitoring capacity around the world?

Every year significant investments are made in hydrometric observation networks around the world. Despite these however many countries still suffer from data gaps. The enhanced hydrological monitoring activities which these projects fund often deteriorate when the initial investments finish. In addition to providing information to help target investment, in establishing the WMO HydroHub, the WMO has argued that there is a need to change the way we support the development of hydrological monitoring capacity to ensure the sustainability of improvements into the future.

Response: Modernizing the WHYCOS framework

Launched in 1993 by the WMO to help overcome the difficulties that many countries faced in the development of hydrological activities, the WHYCOS programme has been running for more than a quarter of a century (Rodda *et al.* 1993, Jarraud 2018). The programme focuses on strengthening national capacities in basic observation, fostering basin-wide, regional and international cooperation and promoting the free exchange of hydrological data. It operates through implementation of regional projects, known as HYCOS components.

Since its formation, over 14 HYCOS components have been undertaken around the world, including multiple phases in some regions (Fig. 2). The programme’s achievements include consolidation/revitalization of hydrometric monitoring sites, technology and knowledge transfer, sensitization of decision makers on the socio-economic input of hydrological monitoring and the development of cooperation between different monitoring agencies. Components operate in a bottom-up approach helping improve monitoring in the field, data processing and network management practices (Fig. 3).

Although the achievements of the WHYCOS programme should not be overlooked, recent assessments of Hydrological Services in developing countries have highlighted the ongoing challenges they face in relation to their observation networks (World Bank 2018, 2019). Findings such as these raise questions about how the way in which we build monitoring capacity can be evolved to ensure long-term suitability but also be scaled-up within the available resources to tackle what is a global issue.

A number of key lessons have been learned from the development of HYCOS components since 1993. Some of these are political and institutional; for example, the importance of political willpower and ownership of the project at a very high governmental level of the participating countries has been demonstrated on multiple occasions. The valuable role of regional/basin institutions as facilitators (of collective actions and knowledge development) and mediators (between countries and with donors), but also as focal centres of competence capable of consolidating the project’s achievements, particularly after its completion, has been shown to be central to ensure sustainability.

The main weakness of the programme has, however, been the lack of post-project sustainability plans for maintenance, including financing, of hydrometric monitoring after the end of the project. It has often not been possible to fully embed the running costs of monitoring within recurrent national regular budgets, meaning that with time, issues arise related to funding equipment maintenance, staff training and software upgrades are all too common.

Notwithstanding these shortcomings, and while the perpetual advances in science and technology mean there is an ongoing need to adjust the programme to achieve better results, WHYCOS’s objectives are still relevant in 2020. Countries and Basin Organizations still consider it as an indispensable tool to help them meet the many challenges of hydrometric monitoring. It is against this backdrop of 25 years of experience and ongoing needs that the WMO HydroHub is now taking the opportunity to modernize and rethink the way HYCOS components will be implemented going forward.

The ultimate objective of the WHYCOS programme is to sustain hydrological monitoring on the basis of regular funding, in particular by promoting the allocation of national budget resources to the monitoring activities, through increased awareness of decision makers of the value of hydrological information. Such funding can only be assured if users of water information are convinced of its necessity and, in particular, of its importance for socio-economic development and, therefore, accept to contribute to it. Therefore, in addition to the free exchange of data, an emphasis will be put on

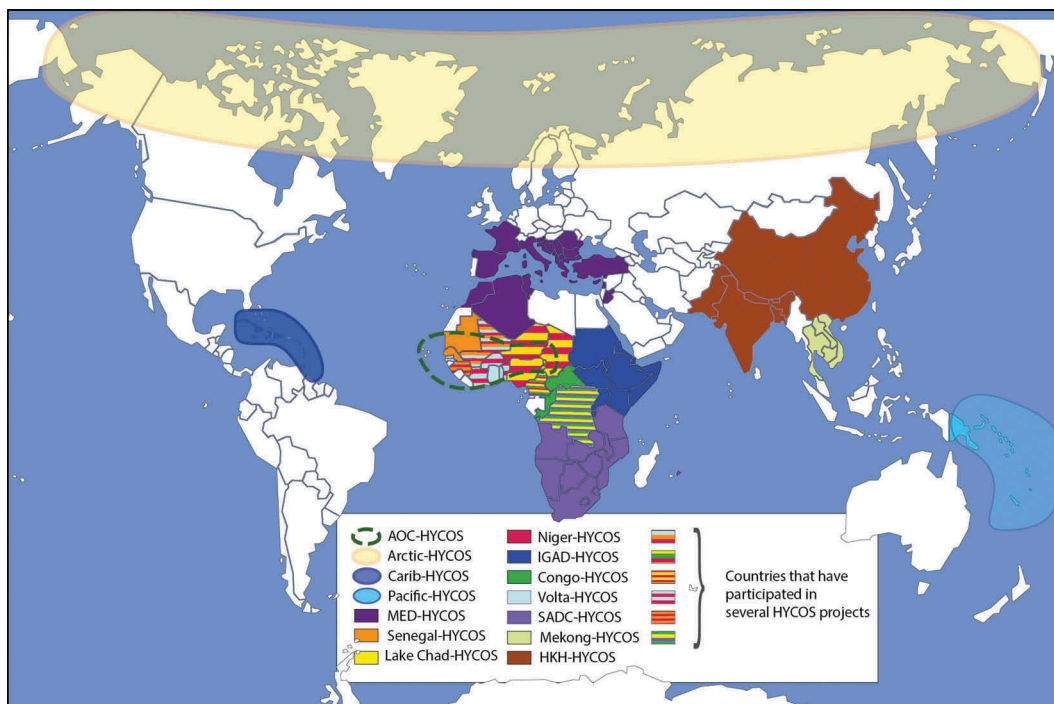


Figure 2. HYCOS components implemented around the world.

establishing links with the users of hydrological products and services for socio-economic development and the reduction of water-related disasters. By integrating support across the value-chain, or data/information life cycle (Dixon *et al.* 2013), future HYCOS components will maximize opportunities for continuous improvements in service provision, which come from better integration with users, and reduce the threats of long-term funding gaps by demonstrating value.

The provision of specific services and products to users (both private and public) will be included in the expected results of the new generation of HYCOS components, so that they can be used by participating NMHSs as demonstration of services provision. In doing so, and to ensure products and services fit users' needs, in-depth organizational and technical assessments of relevant NMHSs, hydrological forecasting agencies, water resource management bodies and Basin Organizations will be conducted at the forefront of any new HYCOS component activity. These assessments of the requirements of countries participating in a HYCOS components may also provide inputs to the wider WMO's Rolling Review of Requirements (RRR) process, by which user requirements for hydrometric observations are compared with the capabilities of present and planned observing systems.

In future beneficiary countries will be expected to contribute from the beginning to the financing of the activities of the HYCOS components to demonstrate their capacity/willingness to continue hydrological monitoring, with their own resources, after the end of the project.

To encourage maintenance of these commitments post project, a long-term support framework for WHYCOS is being

developed which will see WMO more actively involved in assisting countries in the consolidation of the results and the durability of the hydrological monitoring. Ways of making short-term technical support and ongoing training available to the network of completed HYCOS components are being explored. Synergies with other international development financing initiatives, such as Climate Risk and Early Warning Systems (CREWS¹⁷) may also provide the opportunity for interlinked projects whereby the WMO HydroHub focuses on the monitoring aspects that underpin improvements of forecasting and warning services.

Embedding innovation in hydrometry

Extract from the WMO HydroHub Strategic Plan:

“Goal:

The Global Hydrometry Support Facility strengthens fit-for purpose and sustainable monitoring capabilities through innovation in applied monitoring systems for the benefit of local water users and national hydromet services, as well as decision makers at the national, transboundary and global level.”

(WMO 2018b, p. 8)

Question: The research community is generating new sources of water data and innovative sensors, what more can WMO add?

The role of WMO as a global standard-setting body is instrumental in setting the baseline by which WMO Members

¹⁷<https://www.crews-initiative.org/en>.

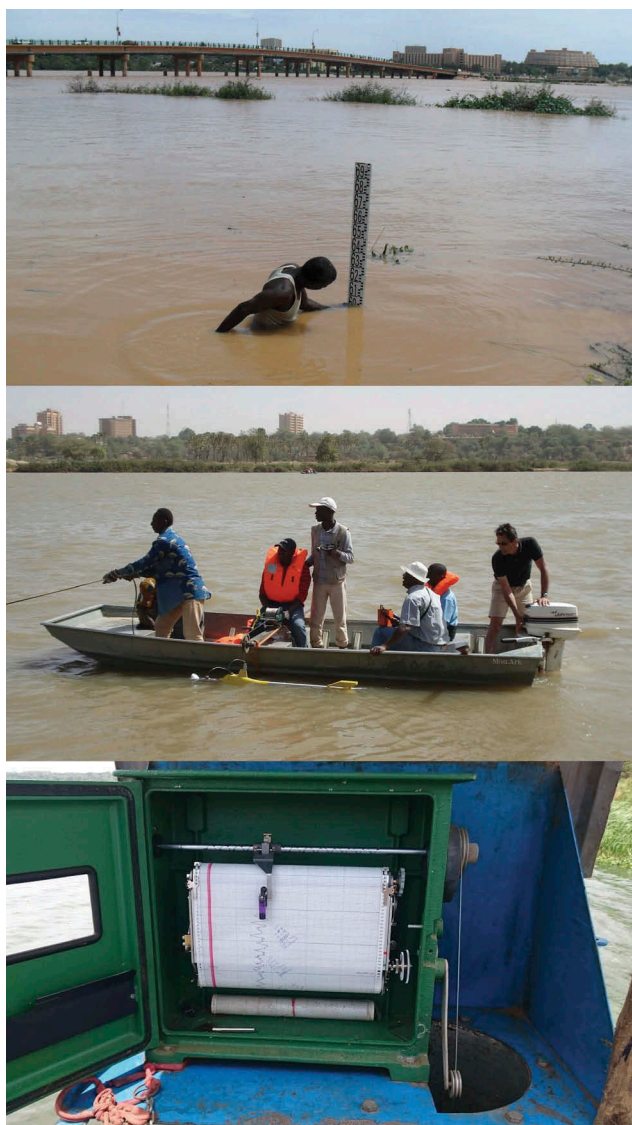


Figure 3. Hydrometric activities in the field (Source: Daniel Sighomnou, WMO Secretariat).

maintain their observation networks and in ensuring that data collection methods are harmonized and fit for purpose. The current fast pace of development in science, sensor technologies, earth observation, IT and communication technologies, together with ongoing societal changes, present enormous opportunities for enriching the quality and quantity of hydrological data and improving the efficiency of monitoring systems (Tauro *et al.* 2018). The operational hydrology community must react to change faster than before in order to take full advantage of new approaches, evolving long-standing observation techniques and management approaches while at the same time maintaining backwards compatibility of data and ensuring reliable information streams. It is important for the reader to understand how the WMO aims to evolve its role in setting the technical norms by which NMHSs operate in order to support innovation in hydrometry.

Response: Supporting the innovation value chain

The WMO HydroHub concentrates on three interconnected Key Innovation Areas: sensor technologies and monitoring techniques – especially low-cost, lean maintenance solutions increase the amount of data collected; data management and dissemination – including software tools and data processing procedures; and monitoring network management processes. Within each area, the WMO HydroHub will help identify specific areas of operational hydrometry where new innovations could support NMHSs in meeting their users' needs.

Part of the focus of the Innovation Hub will be on demonstrating the capabilities of the latest research driven technological developments and approaches within an operational environment – through examples, field trials and training. Improvements in ground- and UAV-based image velocimetry techniques, development of ultra-low power data loggers and increased resolution of satellite-based earth observations, are just three examples of where technological developments may hold great potential for operational hydrometry.

As well as supporting increased uptake of newly developed technologies and approaches for generating hydrometric data, innovation in the provision of hydrological services could include the incorporation of information from more traditional/indigenous practices which have been used to monitor the state of the environment for centuries. Increasing the use of such information, both contemporary and historical, in current service provision could provide significant benefits. For example, by using historical evidence to improve flood-risk estimation.

Whether it is the adoption of cutting-edge technologies or the adaptation of services to benefit from older advances, central to the WMO HydroHub's approach to hydrometric innovation is the blending of support for technical development with activities which help organizations create environments that embrace new solutions, processes and management paradigms for the advancement of operational hydrometry. For many, a cultural change is needed towards more openness to partnering and collaboration, adopting fast and agile 'trial-and-error' development paths and evolving management practices to optimize the day-to-day collection of observations.

Rapid organizational change is difficult to achieve. While the WMO HydroHub will demonstrate the benefits that could stem from the adoption of new methods and tools, implementing an environment that embraces continuous evolution will likely demand a new set of competencies from the staff of the Hydrological Services, something which will be reflected in the new version of the "WMO Standards for Education and Training in Hydrology", currently under revision. In regard to the effective development and delivery of education and training, the WMO HydroHub will benefit from the WMO Global Campus initiative.¹⁸

Often these non-technological elements of innovation present some of the greatest challenges to the long-term sustainable adoption of hydrometric innovation. Put simply, for the WMO community, isolated examples of new sensor deployment or the coding of a new open-source data management systems are not enough. In order to facilitate a step change in

¹⁸<https://tinyurl.com/ydbeb3uy>.

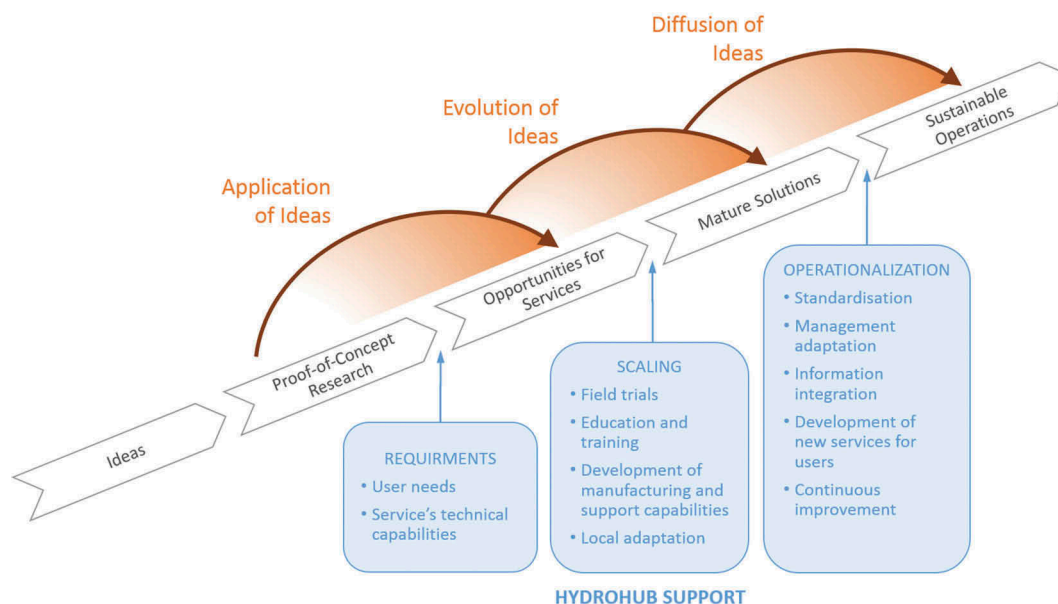


Figure 4. Focus areas for WMO HydroHub's support within the wider innovation development chain in hydrometry.

the quantitative information that underpins water management, the focus must also be on building the capacity of monitoring services to finance, rollout and maintain new technologies. Such support should enhance the flow of ideas into sustainable operations, through the innovation chain (Fig. 4).

While the one-off adoption of an innovation may provide short-term benefits, it is the sustained capacity to adapt to a changing environment that allows successful organizations to stay at the top. For this reason, the WMO HydroHub will place particular emphasis on activities that build long-term innovation capacity within the global operational hydrometry community encouraging them to continuously assess and integrate opportunities arising from new developments.

To embed the skills and culture needed to innovate within operational services, the WMO HydroHub is developing mechanisms including innovation workshops, camps and calls. Workshops bring communities together to explore new ways to collaborate and foster transfer of knowledge on needs and new capabilities – for example, between academia and national services. Innovation Camps, in the shape of hackathons, data deep-dives or field testing, will allow groups of individuals to work intensively on a specific issue over the course of about a week and can deliver fast insight in a new technology. A change of innovation culture towards more user-centricity, partnering and direct impact is a long-term goal that cannot be achieved by the WMO HydroHub alone. At the same time as changing culture and building innovation skills, support for evolution of ideas beyond proof-of-concept is being provided by the Hub's Innovation Calls where a financial award is offered to projects that tackle particular challenges related to idea scaling, such as developing the local manufacturing and support needed for new hydrological sensor technology.

The operationalization of mature solution will be supported, in part, by consideration of what barriers to innovation might inadvertently exist within WMO's own technical standards and

regulations – which cover both observation practices and NMHS management. When setting up operational monitoring procedures and making decisions around equipment procurement specifications, many NMHSs look to internationally agreed standards for guidance. In the field of hydrometry, the most heavily used international standards are those produced by the International Organization for Standardization (ISO) and WMO. The technical recommendations contained in these standards provide an essential basis for ensuring the quality and interoperability of the hydrometric monitoring data produced by NMHSs and as such underpin their provision of reliable and trusted services which inform water management (Stewart 2015). Considerable effort is invested by hydrometric experts around the world to maintain such standards. The nature of the international decision-making process however means that the revisions and publication of updated standards takes time. There can be a lag between the initial operational implementation of new techniques/equipment and the point at which uptake is widespread enough around the world for standards to be updated. As such, while vital for ensuring a consistent baseline in data quality, standards can at times present a barrier to innovation in operational practices.

The WMO HydroHub aims to consider how best the international community can strike a balance between providing standards which help raise the quality of global hydrometry while at the same time fostering faster uptake of innovative monitoring approaches. The WMO's own technical standards and guidelines for service provision will be reviewed to identify any such barriers and consideration given as to how to remove (or minimize) them in future updates. For example, the WMO HydroHub might promote exploration of issues related to how to compare and communicate measurement uncertainty in a way which allows NMHSs to integrate information from different sources into existing, and new, services (such as flood warning and water resources assessments) which are delivered under defined quality management frameworks.

Much like the innovation chain it seeks to enhance, the WMO HydroHub's way of supporting new approaches around water data are continuously evolving but at their core are guided by the principle that innovation must be pursued for a reason. It is not enough to collect new data: we must also make the resulting information available by transforming it into products and services that support evidence-based decision-making for good water governance.

Success will be determined by the value added for practitioners – for example, the new data that are made available to more stakeholders, the services which are delivered to users with greater efficiency and reliability or the new solutions re-used to add value in other contexts.

Enabling hydrometric data sharing

Extract from the WMO HydroHub Strategic Plan:

“Goal:

The Global Hydrometry Support Facility supports the free and open sharing of hydrometeorological data around the world.”
(WMO 2018b, p. 9)

Question: Free and open data has long been an aspiration for many in hydrology, what new approaches will the WMO HydroHub adopt?

Easy access to hydrological data without payment is often cited as a key constraint on both operational and research hydrology. As the key intergovernmental body engaging with those who undertake much of the world's quantitative hydrological observations, WMO has for many years explored ways of ensuring that where such data needs to be exchanged there are mechanisms in place to do so. Of course, this challenge is not just technical but also political, economic and cultural. The WMO HydroHub must do more than just providing the sensor networks, information technology infrastructure and data standards needed to share water data.

Response: Evolving policies and technologies to meet local and regional needs

Data exchange policies

The exchange of hydrological data beyond national, and sometimes institutional, boundaries has often been limited. The focus of the operational hydrology activities they were supporting was traditionally confined within the national, or even sub-national limits, and even data exchange in shared transboundary rivers was far from being a commonly accepted practice.

In recent decades, however, the drive towards fostering the international exchange of hydrological data, beyond the traditional boundary of national borders and institutional jurisdictions has been increasing. In part the demand to collate data over larger geographical areas of the globe has been fuelled by wider societal and technological changes to exchanging information more openly and easily – the availability of earth

surface mapping data via platforms such as Google Earth being one such example.

In hydrology this demand is also driven by our need to understand and manage water resources and associated risks in new ways. For example, if we are to better understand the impacts of a changing climate on the water cycle as a whole, we must integrate data across the whole Earth system. Similarly, the rising global population is placing more demands on agricultural systems enhancing our need to integrate water demand and availability data to help manage their vulnerability to drought. Combating such growing threats has enhanced the demand for integrated catchment-wide solutions that span political or organizational boundaries. Environmental regulations and international agreements are also feeding the appetite for water data. In Europe, the EU Water Framework Directive placed reporting requirements on national governments to improve catchment management and more recently the adoption of the SDGs and other global or regional commitments for Disaster Risk Reduction is leading to a growth in internationally agreed indicators in the water sector.

Within WMO, a key step in the direction of enhanced data exchange was the adoption in 1999 by WMO Congress of the Resolution 25: “Exchange of Hydrological Data and Products” (WMO 1999). This resolution set a general framework to broaden and enhance the free and unrestricted international exchange of hydrological data and products. In particular if focused on information necessary for the protection of life and property and for the well-being of all people, as well as those hydrological data and products required to sustain international programmes and projects related by the research and education communities.

In some parts of the world, while the direct impact of this resolution on nation-to-nation data sharing has been limited, some of the secondary impacts have shown more promise. Based on the principles set by Resolution 25, and its sister resolutions on meteorological and climatological data (WMO 1995, 2015), some regional institutions and transboundary river authorities have developed and adopted their own specific agreements. These localized applications of the globally agreed principles for exchange, allow those producing and using the data to tailor the type, frequency and characteristics of data and information concerned to their specific requirements. As a result, the agreements are based not only on large-scale requests for data publication but also upon immediate local needs which managers and NMHS Directors can justify to their funders and Governments.

The first example of such an approach was the “Policy on the exchange of hydrological and meteorological data and information in the Sava River basin” adopted by the international Sava River Basin Commission in 2014 (International Sava River Basin Commission 2014, Dixon *et al.* 2018). This approach serves as a reference for further formulations that the WMO HydroHub will support over the coming years.

Data exchange technologies

At the same time as policies and attitudes to hydrological data exchange are becoming more liberal, the capability of information technologies to enable such transfer are significantly increasing. More and more NMHSs have started making their

data and information freely available on their web sites and via web services. While the amount of hydrological data openly available from operational Services is growing, two key issues remain. Firstly, barriers due to difference in format, presentation, language, etc. continue to limit the discoverability and interoperability of those data resources that are published. Secondly, there remains a significant sub-set of the global NMHS community which still has difficulties in participating in this global data endeavour. The lack of proper database management systems impacts upon the storage and analysis of their data, out of date technical capabilities mean they struggle to make data available on the Internet in a timely manner, and limited human and financial resources present challenges in keeping up with ever-changing technologies.

To overcome these barriers WMO has developed a two-pronged approach that the WMO HydroHub will pursue: on the one hand, supporting the development and implementation of free and open-source data management systems and on the other, developing a global data exchange framework to facilitate hydrological data discovery and access.

The MCH (Meteorology, Climatology and Hydrology) is a licence-free Database Management System (DMS) made available upon request to WMO Members' NMHSs. Acting as a support tool for improving data management, MCH allows NMHSs that never used this kind of technology, to both secure their historical data as well as familiarize themselves with the deployment of such technologies within their operation services. For some it may provide a stepping-stone to more advanced DMSs that are available on the market, while for others it provides a vital free-to-access tool which will continue to underpin their data operations into the future. Consideration is being given as to how best to support the ongoing development of MCH, ensuring it keeps pace with technological and hydrological advances. To help with this, a community of developers, trainers and implementers has been established, to make sure new functionality addresses users' needs and provide support in better tailoring implementation of the system to local requirements. This globally distributed team will also help to maintain skills within the regions using MCH most heavily, thus ensuring more accessible support in the long term.

To improve the discoverability and exchange of hydrological data provided by NMHSs, the WMO has initiated WHOS. The system provides a multi-scale (local, national, regional and global) registry of hydrological data and information services catalogued using the standards and procedures developed by the Open Geospatial Consortium (OGC) and the WMO (Pecora and Lins 2020). Linkages to the Group on Earth Observations (GEO), which provides the GEOSS technology¹⁹ and a very successful community-based approach to data collection and dissemination, are being evaluated.

This registry will be open to all users and institutions from any country or level of government and can handle any type of hydrological information.

The WHOS is being developed and implemented in two phases: Phase 1 was completed in 2016 and provides a map interface²⁰ with links to those NMHSs that make their real-time and historical hydrological data available online.

Phase 2 provides a fully WMO-compliant services-oriented framework linking hydrologic data providers and users through a hydrologic information system enabling data discovery and data access. Once discovered and accessed, data are then automatically converted into standardized hydrological data exchange format (WaterML 2.0). Phase 2 is fully compliant with the WMO Information System (WIS²¹), the single coordinated global infrastructure responsible for the telecommunications and data management functions that help WMO Members exchange observational data and products.

Where implemented, WHOS allows the free and open exchange of hydrological data in a manner that makes them easily usable in any applications complying to WaterML 2.0. Regional prototypes are being developed for WHOS Phase 2 in the Arctic, La Plata Basin in South America and Sava Basin in South East Europe, with an aim of wider rollout in the coming years. Implementation of the WHOS Phase 2 prototypes, including substantial capacity development activities to ensure long-term sustainability, is driven and carried out by participating countries in accordance with their local and regional requirements.

Taken together, the strategy of increasing access to critical base line data management technologies while also advocating the use of modern data interoperability and exchange technologies by NMHSs, is designed to ease the burden to operational services who wish to share their monitoring information. Coupling this with the support for needs-driven, bottom-up data exchange policies, the WMO HydroHub will hopefully help ensure that observational data reaches those who need them to manage and understand freshwater systems.

Connecting the global water monitoring community

Extract from the WMO HydroHub Strategic Plan:

“Goal:

The Global Hydrometry Support Facility supports improved collaboration and information sharing within the NMHS community in order to increase the quality and sustainability of water monitoring.”

(WMO 2018b, p. 10)

¹⁹<https://www.earthobservations.org/geoss.php>.

²⁰<https://tinyurl.com/vpefn4u>.

²¹<https://tinyurl.com/rwftm>.

Question: In the age of global connectivity, what new connections are needed to help hydrometric practitioners around the world?

The ability for individuals to connect with each other either virtually or in person has never been easier. In a specialist technical area such as hydrometry however, finding someone with the right expertise who can offer assistance can still be a challenge. This question is designed to help the reader understand what more the WMO HydroHub aims to provide over and above what can be achieved via normal communication methods and existing fora.

Response: Better peer-to-peer connections and learning opportunities that are based on reflection and shared practice

According to the Global Facility for Disaster Reduction and Recovery (GFDRR) and the World Bank (2018), one of the principal barriers to the continuity of hydrological data gathering and monitoring, is the limited capacity of field hydrologists to cope with modernization and sustainability of enhanced monitoring systems. Traditional methods of learning through education and professional training courses remain one answer to this issue and the vast array of online reference material provides a more recent and useful additional tool for updating knowledge. In a fast-moving technological field such as hydrometry, however, courses and published guides often cannot keep up with the rate of change. Added to this, the variable nature of fluvial systems and need to tailor observation solutions to local conditions means that the hydrometric challenge facing operational agencies can vary significantly. There may well not be a textbook available that answers the specific question about shifting rating curves that you are facing or a colleague on-hand locally who has faced the same sensor malfunction issue.

Better peer-to-peer connections between hydrometric practitioners all around the world and learning opportunities that are based on reflection and shared practice are vital to tackle day-to-day operational challenges faced by NMHSs, especially those related to new practices and technologies. To advance this, the WMO HydroHub is developing a Community of Practice (CoP) for Hydrometry. As a concept, Communities of Practice are “groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis.” (Wenger *et al.* 2002, p. 4). When successful they provide a support ecosystem for their participants, helping them in tackling issues however small or large.

The CoP for hydrometry being developed at WMO will provide an online platform for discussion amongst hydrometric practitioners, experts, researchers, students, and other concerned and interested individuals, focusing on facilitating rapid online assistance amongst participants. Two of the key target communities for the CoP participants are academia and private sector providers of monitoring solutions. It is hoped that they will convey innovation and the latest solutions available to operational services, but also use the CoP as a source of information regarding NMHS needs and feedback on current

practices. Cultivating this knowledge sharing within the CoP, will promote a closer relationship between operational hydrometric technicians and those offering solutions. Preserving such information within the CoP will allow the creation of a unique solution portfolio for the challenges and efficiency barriers to hydrological data collection, management and use.

The CoP will be a global connector for solution-oriented knowledge, contacts, good practices and lessons learned in all areas of hydrometry, allowing continuous collective learning and collaboration. Being a user-driven collaboration platform, the CoP will facilitate the sharing of ideas among participants boosting co-creation of new solutions and rapid response support.

Conclusions

Despite decades of concerted effort to facilitate building the hydrological monitoring and related database capacity necessary for addressing local to regional needs for managing water resources and mitigating water related hazards, particularly in the developing world, results have been limited and lacked sustainability. Realizing the evolving imperative for sound and accessible water data and information to meet expanding needs worldwide, the Countries and Territories who are Members of WMO have embarked on a new intergovernmental endeavour, building on the lessons learned over the past three decades, to develop an innovative and more comprehensive approach to supporting capacity development in hydrometry – the WMO HydroHub.

This new approach couples a framework for supporting operational hydrometric systems with technological innovations in monitoring, database development and free and open data sharing worldwide and, critically, improved collaboration and information sharing through a Community of Practice involving peer-to-peer support. In this way, a multi-faceted mechanism of support, extending far beyond the traditional donor-recipient model, will be employed to provide NMHSs, particularly in developing countries, with the type of assistance and services that have been identified as lacking in previous capacity development efforts. As of this writing, the WMO HydroHub is transitioning from the preparation phase to the implementation phase, so the curtain is now rising on a more coordinated and cooperative approach to hydrometry and data sharing whose performance will be easy to track in the coming years.

What then, will the hydrological monitoring and data/data-sharing landscape look like in 2030 if the goals of the WMO HydroHub are achieved? First and foremost, there will be a significant increase in the availability of quality-assured hydrological data over areas of the world where such data are currently lacking or unavailable. Second, the number of monitoring stations continuing to operate beyond the period of donor funding (i.e., being supported directly by the NMHS or cooperating government agency) will be increasing. Third, a broad expansion in partnerships across the entire water monitoring enterprise should be evident.

These are all achievements for which metrics can and should be defined, implemented and tracked to ensure that

the WMO HydroHub is, indeed, achieving the requisite improvements to enable NMHSs to meet the expanding water challenges of the 21st century.

The expansion of partnership is a key step in realizing the other achievements. This includes partnerships within the operational hydrometry community, with greater peer-to-peer support across NMHSs to address needs associated with water monitoring technologies, data management systems, and education and training. But, critically, it must also include much more collaboration between NMHSs and: (a) the communities developing innovative technologies; (b) regional water and disaster management organizations to facilitate data sharing and problem solving; (c) local water users to increase community engagement in water issues; and (d) national and transboundary entities tackling shared problems at large scales.

Crosscutting all of these partnerships must be a desire to increase the understanding of, and value that society assigns to, operational hydrometry. This paper aims to take a first step in this direction by raising awareness in the global hydrological sciences community regarding the multilateral initiatives that governments are putting in place around water monitoring, helping those who use water data understand what, why and how the UN system is supporting hydrometry.

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