

## Over 25 years of FRIEND-Water: an overview

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**Abstract** FRIEND-Water has been a flagship programme of the UNESCO-International Hydrological Programme (IHP) for more than 25 years. This network has delivered outstanding scientific value (research papers, conferences) and made significant contributions to international cooperation in the water sciences and associated water resources management, an objective at the core of the IHP and UNESCO mandate. An overview of major activities and outcomes from this cross-cutting programme is provided, including database progress, enhanced scientific understanding of hydrological processes across scales, development of analytical tools, education, capacity building, dissemination and cooperation with other networks. The programme is not only a network of scientists; it is also aims to be a network of several databases and institutions. Ongoing and future activities of the FRIEND-Water network are also addressed.

**Key words** regional hydrology; flow regimes; hydro-extremes; water resources; databases; education; capacity building; dissemination; international cooperation

### BACKGROUND

In 1985 a research programme was initiated as a follow-up of the UNESCO International Hydrological Decade (IHD) 1965–1974. During the IHD, a number of research basins were established around the world and a variety of scientific studies were conducted. However, only a few studies worked across national boundaries (i.e. at the regional scale). This apparent lack of international comparative analysis was the impetus for establishing the FRIEND-Water (Flow Regimes from International and Experimental Network Data) programme, as an international collaborative research initiative under the umbrella of UNESCO's International Hydrological Programme (IHP). FRIEND-Water aims to develop a better understanding of hydrological variability and similarity across scales through exchange of data, knowledge and techniques. This has been a continuous effort over more than 25 years. Sharing of data, models and research tools between countries, organizations and researchers has always been a high priority for the FRIEND-Water programme since it helps to advance science and to bridge the gap between research and operational water management. A large number of universities, research institutes and water-related agencies in over 150 countries around the world have actively participated. It became a worldwide programme, not only with respect to its geographical coverage, but also due to the vast number of well-recognized publications in international journals, its attractive training courses for students and water managers around the world, and by offering an international network for young researchers.

The current FRIEND-Water programme aims at improving water science and sustainable use of current and future water resources. The programme achieves these goals through:

- (a) collecting and exchanging environmental (mainly river flow) data, particularly in an international context;
- (b) enhancing scientific understanding of hydrological processes across scales from local up to global;

- (c) developing innovative analytical tools for further improvement of water resource management and reduction of hydrohazards' risk (i.e. floods and droughts);
- (d) educating and developing capacity building pathways through PhD and MSc courses and technical training courses; and
- (e) disseminating knowledge through journal publications, books and manuals, conferences, technical workshops and web-based platforms, to cooperate with other international networks and professional organizations, and recently to be active in science-policy-making.

With eight regional groups (Fig. 1), FRIEND-Water reflects the best in international cooperation between scientists, water managers, stakeholders and policy makers.

The following section highlights some major achievements of the FRIEND-Water programme, before the last section concludes with some on-going and future activities, which only can be achieved through a well-linked international science network.

## MAJOR ACHIEVEMENTS

### Databases

The FRIEND-Water programme has collated river flow data for different regions of the world. In addition to flows, an inventory of river basin properties was compiled to provide thematic and metadata to aid interpretation of hydrological response and spatial variability. The regional databases have grown over the years and are updated regularly to meet modern research needs. Hannah *et al.* (2011\*)<sup>1</sup> highlighted the importance of large-scale river flow archives for evidence-based assessment of past hydrological variability, and for supporting hydrological modelling of future changes. They highlighted the FRIEND-European Water Archive (EWA) as an example of a valuable transnational data resource for basic and applied hydrological research.

### Increased scientific understanding

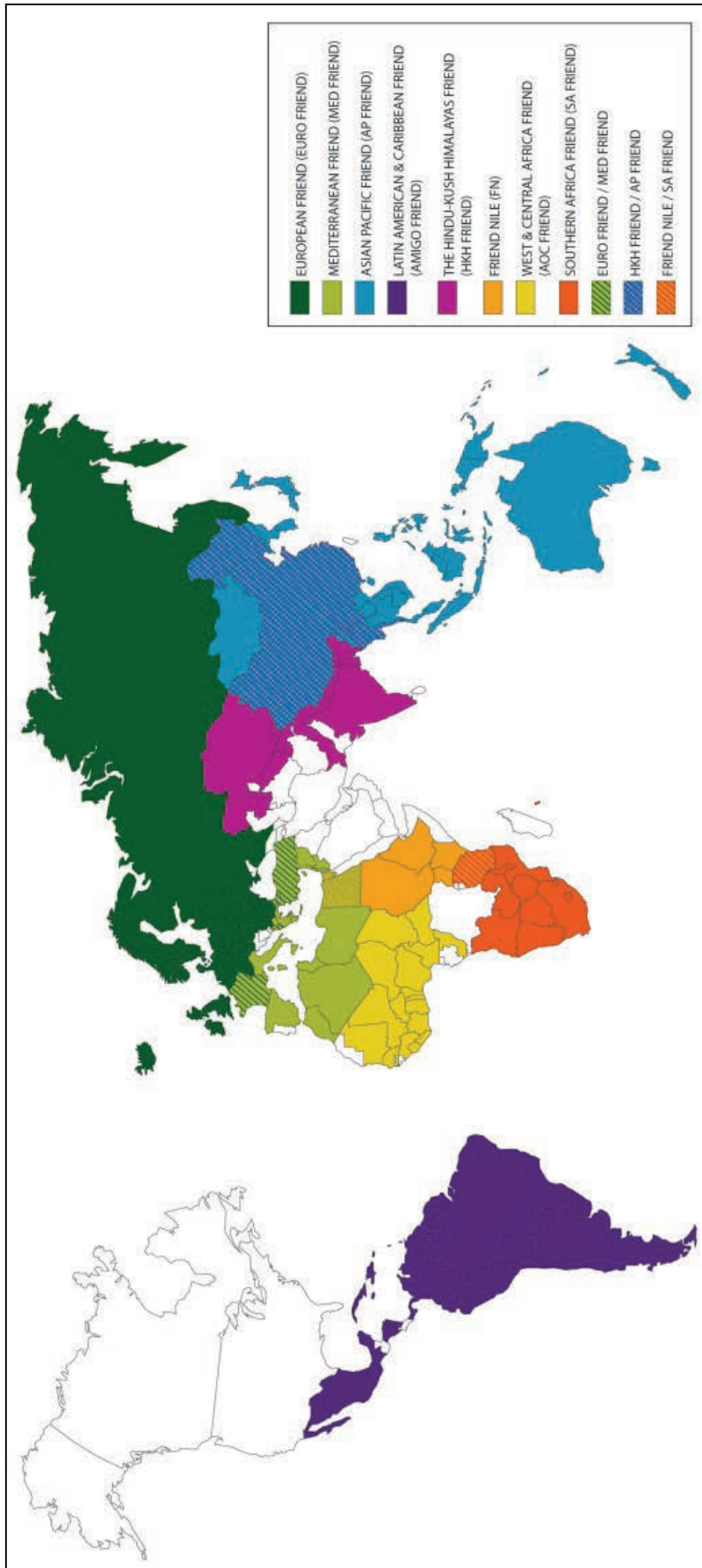
This section provides examples of increased scientific understanding, without attempting to be inclusive. Van Lanen & Demuth (2014) give a comprehensive overview of FRIEND-Water publications from the different regional groups which have been published in the period 2010 to 2013, and it provides reference to FRIEND-Water publications from previous reporting periods.

**Hydrohazards** A key research topic of the FRIEND-Water programme is hydrohazards: both floods and drought. The impressive progress in the flood field has recently been synthesised by Simonović (2013\*) and others in a collection of four books on flood disaster management theory and practice within the context of anthropogenic climate change. The books include: (a) flood forecasting and hydrological processes linked to heavy rainfall, (b) stochastic modelling of heavy precipitation for runoff forecasting, (c) tools for warning and forecasting in ungauged basins, including hydrological and inundation modelling, (d) enhanced understanding, forecasting and management of flash floods in urban areas, and (e) development of methodologies for reliable inundation mapping, and development of flood risk and vulnerability maps.

AP-FRIEND has conducted a number of workshops bringing together countries across the region to address Rainfall Intensity Duration Frequency (IDF) analysis for the Asia Pacific Region (Daniell & Tabios, 2008\*) and conversion of these values using flood estimation and flood hydrograph procedures (Daniell, 2011\*) as this was seen to be important for lessening damage from disasters by relevant design of infrastructure for floods.

The FRIEND-Water program has been performing pioneering work on low flows and drought hydrology. The core focus on data networks of FRIEND-Water laid the foundation for the first regional low flow studies yielding enhanced understanding of low flow generating processes,

<sup>1</sup> References marked with an asterisk (\*) have been included in the FRIEND-Water overview report (Van Lanen & Demuth, 2014), and are not listed under References in this paper. Full description of all references in this paper is also available at: <http://www.wageningenur.nl/en/Show/References-IAHS2014-Paper.htm>.



**Fig. 1** FRIEND-Water Regional Groups and their geographical coverage.

catchment similarity, and estimation procedures on a regional scale, long before being on the agenda of any other international activity. Through this core expertise, the FRIEND-Water network significantly contributed to the success of: (a) the WMO *Manual on Low-flow Estimation and Prediction* (Gustard & Demuth, 2009), and (b) the recent IAHS decade to assess current state-of-the-art of low flow prediction in ungauged basins (PUB, Laaha *et al.*, 2013\*). Later, pioneering work has been done on drought hydrology. These recent achievements have extended the earlier overview work of Smakthin (2001\*) and show that low flow modelling still needs improvement (e.g. Staudinger *et al.*, 2011\*). The FRIEND-Water network initiated research on: (a) definition and development of drought identification methods (e.g. Fleig *et al.*, 2006\*; Van Huijgevoort *et al.*, 2012\*), (b) streamflow deficiencies and circulation patterns (e.g. Stahl, 2001\*; Fleig *et al.*, 2011\*), (c) propagation of meteorological drought into hydrological drought, and the associated development of a process-based drought typology (e.g. Peters *et al.*, 2003\*; Van Loon & Van Lanen, 2012\*), (d) spatio-temporal drought development (e.g. Peters *et al.*, 2005\*; Tallaksen *et al.*, 2009\*, Hannaford *et al.*, 2010\*, Corzo Perez *et al.*, 2011\*), and (e) trends in low flows and drought (e.g. Hisdal *et al.*, 2001\*; Hannaford & Marsh, 2008; Stahl *et al.*, 2010\*; Wilson *et al.*, 2010\*; Stahl *et al.*, 2012\*; Hannaford *et al.*, 2013\*). This vast scientific achievement also led to a better assessment as to what extent global models used for climate change assessment capture drought (Prudhomme *et al.*, 2011\*; Stahl *et al.*, 2011; Gudmundsson *et al.*, 2012a\*,b\*; Van Loon *et al.*, 2012\*; Van Huijgevoort *et al.*, 2013\*).

**Large-scale hydrology** Recent FRIEND-Water research has made significant contributions to advancing knowledge of: (a) flow regimes and climate-hydrology interactions across Europe (e.g. Lavers *et al.*, 2013\*), the North Atlantic (e.g. Kingston *et al.*, 2011\*), UK (Lavers *et al.*, 2010\*), and other parts of the world such as the Mediterranean (e.g. Saris *et al.*, 2010\*; Milano *et al.*, 2012\*) and West and Central Africa (e.g. Ardoin-Bardin *et al.*, 2009\*), (b) the role of river basin properties in modifying hydrological response (e.g. Laizé & Hannah, 2010\*), and (c) links between large-scale climate patterns and hydrological extremes (e.g. Kingston *et al.*, 2013\*). We believe the breadth of these contributions demonstrate a move towards a more interdisciplinary and united approach (including combining empirically-based and modelling studies) to understanding hydrology at large-scales that will underpin major future research advances (Cloke & Hannah, 2011\*).

**Semi-arid and coastal hydrology** Semi-arid areas in Africa faced both a rainfall decrease and an increase of population and associated agricultural activities, which led to a rapid degradation of land cover. The regional FRIEND-Water groups in these dry regions (AOC FRIEND and MED FRIEND, Fig. 1) study erosion and sediment transport as they are major issues for development. Most sediments are trapped into dams and lakes and thus do not reach the sea, moreover many controlled rivers have reduced outflows. This has great impact on coastal ecohydrology, and in many places, including RAMSAR sites, changes in water quality and in coastal geomorphology are observed, endangering the sustainability of environmental resources and ecosystems, and increasing their vulnerability to sea level rise. Research topics in the dry regions concentrate on erosion and sediment flux modelling, with an emphasis on multidisciplinary approaches, but impact of extreme events, and coastal biogeochemical changes linked to human activities was also studied (Mahe *et al.*, 2010).

Research has clearly benefited from scientists being a member of an international network such as FRIEND-Water. The participation of many FRIEND-Water programme members in internationally-funded research projects (e.g. ARIDE, GRAPES, ASTHyDA, WATCH, SPLASH, XEROCHORE and DROUGHT-R&SPI) demonstrates the advantage of holding such membership.

### **Innovative analytical tools**

Various analytical tools have been developed by the FRIEND-Water programme. For example, a CD with analysis tools (<http://www.geo.uio.no/edc>), including data, worked examples and guided tours accompanied a textbook on *Hydrological Drought* (Tallaksen & Van Lanen, 2004\*).

Additional tools were made available by the *Manual on Low-flow Estimation* and through a web-based, user-friendly software package, *lfstat* (<http://cran.r-project.org/web/packages/lfstat/>). The manual has a practical approach targeted to meet the needs of national hydrological and meteorological services (Gustard & Demuth, 2009).

### Education and capacity building

The FRIEND-Water programme developed comprehensive course material and has conducted over 30 courses on various topics to about 530 participants from >100 countries (Table 1).

**Table 1** FRIEND training courses by topic and region, 1995–2010/2012.

Region	Number of courses	Number of countries involved	Number of participants	Topics
EURO FRIEND	5	35	106	Low flows and droughts
MED FRIEND	2	11	39	Low flows, GIS
SA FRIEND	6	8	90	Data, GIS, extremes, modelling
HKH FRIEND	11	10	177	Low flows, sediments, water quality, mass balance monitoring of glaciers, database
NILE FRIEND	3	10	30	Floods, droughts, modelling
AP FRIEND	3	20	45	Floods, water resources management, low flows
AMIGO FRIEND	1	12	20	Low flows
AOC FRIEND	2	15	24	Data analysis, GIS
Total	33	121	531	

FRIEND-Water activities include capacity-building through: (a) sponsored studentships (e.g. the Norwegian NUFU Water-Sciences project), and supervision of local postgraduate researchers. Capacity building is also facilitated through joint research projects between partners from developed and less developed nations; here the FRIEND data and research and training networks play a key role. The Hindu Kush Himalayan (HKH) region, as an example, closely cooperated with CEH Wallingford on regional hydrology and options for hydropower generation. AOC FRIEND and MED FRIEND helped participants in Africa and the Mediterranean through international courses and workshops, the use of analytical tools for data series analyses, such as MVR (regional vector method) and Khronostat (trends and ruptures analysis), developed by IRD.

### Dissemination

FRIEND-Water has generated several hundred publications in peer-reviewed scientific journals (Van Lanen & Demuth, 2014). The network programme helped to disseminate the research results by convening well-known international scientific conferences every 4 years. It has organized international workshops jointly with professional organisations, such as IAHS and held numerous sessions at the European Geophysical Union (EGU) assemblies. The meetings help to give the FRIEND-Water community the opportunity to exchange experience and knowledge beyond the scope of their own programme.

Through the virtual European Drought Centre (EDC, <http://www.geo.uio.no/edc/>), which aims to promote collaboration and capacity building between the scientists and the user communities, FRIEND-Water participants contribute knowledge and skills on low flows and droughts.

There are growing efforts of the various regional FRIEND Water groups to feed scientific information into the design, implementation and review of water policies of national governments,

and international policy frameworks (e.g. EU Water Framework Directive, WFD). A common output from this science–policy interfacing is Science Policy Briefs<sup>2</sup>.

### Cooperation with other networks

The FRIEND-Water programme is linked to many international programs and professional organisations within the international hydrological community, and interacts with other IHP technical programmes (e.g. International Flood Initiatives (IFI), International Drought Initiative (IDI), International Sediment Initiative (ISI)). For instance, the programme helped IFI to promote the paradigm shift from flood management as a strategy of defence, towards the transsectoral and transdisciplinary approach of integrated flood management to maximize the long-term benefits of floods and to minimize the hardship, loss of life and damage to goods and assets that result from floods. FRIEND-Water has productive links with other UN organizations (e.g. WMO, UN-ISDR, WWAP) and professional scientific organizations (e.g. IAHS, EGU, ICSU). Close co-operation developed, in particular with the World Meteorological Organization (WMO), through the Commission for Hydrology Programme on disaster mitigation on floods and droughts, the Hydrology and Water Resources Programme (HRWP) and the World Climate Research Programme (WCRP). In West and Central Africa the AOC FRIEND research community was associated with the international AMMA experiment on monsoon flow (2001–2010). In the Mediterranean the new network of the lagoons of Maghreb (MAGHLAG), which is associated with the EUROMEDLAG network, has begun to collaborate with MED FRIEND.

### ONGOING AND FUTURE ACTIVITIES

**Databases** Current activities concentrate on the harmonization of the databases and establishing interfaces to provide easy access to the scientific community. The various regional FRIEND-Water databases are planned to become an integral part of the Global Runoff Data Centre (GRDC) of WMO hosted by the Federal Institute of Hydrology in Koblenz, Germany. Different databases are being aligned (e.g. the FRIEND-Latin America and the Caribbean Database system with the AOC FRIEND and the MED FRIEND database architecture and the European Water Archive, EWA). An initiative has begun to yield a joint FRIEND Data Portal to provide easy access for researchers to the different regional FRIEND-Water Archives.

**Research** The different groups, which may have a different research focus due to the specific challenges of the regions (Table 2), will continue to enhance knowledge. Research will address future challenges, in particular making use of the unique databases of streamflow observations and their potential for large-scale analysis of spatial and temporal variability, as well as for use in model validation studies. FRIEND-Water is identified in the UNESCO IHP-VIII (2014–2021) strategic plan “Water security: responses to local, regional and global challenges” as one of two cross-cutting programmes. It interacts with all IHP themes, such as water-related disasters and hydrological change, water scarcity and quality, ecohydrology, groundwater in a changing environment.

**Education, capacity-building and dissemination** These activities are intrinsic parts of the FRIEND-Water programme under the umbrella of UNESCO. It will contribute to: Water Education, key for water security (Theme 6, UNESCO IHP-VIII, 2014–2021).

FRIEND-Water with its extensive and huge network of researchers and its excellent scientific record and hydrological databases, is the most successful hydrological programme within the entire UN system. Despite all the constraints an international programme faces, FRIEND-Water will continue to create new grounds for international cooperation across political frontiers and be a platform for young scientists to work across national boundaries. However, challenges still remain,

<sup>2</sup> The XEROCHORE project had a major outcome a number of Science Policy Briefs in four languages; each of them addressed a certain WFD article (<http://www.feem-project.net/xerochore/downloads.php>).

for instance: (a) regular updating of databases, (b) secure research funding, particularly in less developed countries, and (c) revitalising FRIEND-Water in some regions because not all regions are equally active.

**Table 2** Main research themes of the regional FRIEND-Water groups (see Fig. 1 for acronyms)

Main research themes by regional FRIEND groups	EURO	MED	SA	AOC	NILE	HKH	AP	AMI-GO
Database	✓	✓	✓	✓	✓	✓	✓	✓
Low flows and droughts	✓	✓	✓	✓	✓	✓	✓	
Regime variability and large scale hydrological variation	✓	✓		✓		✓		✓
Change detection and attribution	✓							
Techniques for extreme rainfall and flood runoff estimation	✓	✓	✓	✓	✓	✓	✓	
Rainfall-runoff modeling	✓	✓	✓	✓	✓	✓	✓	
Physical processes of streamflow generation in small basins	✓							✓
Catchment hydrological and biogeochemical process in a changing environment	✓							✓
Karstic hydrogeology		✓						✓
Erosion and solid transport		✓	✓		✓			
Water quality				✓		✓		
Snow and glaciers						✓		
Integrated catchment management		✓			✓	✓		
Human influences	✓						✓	✓
Information management						✓	✓	✓
Water resources assessment		✓	✓			✓	✓	✓
Coastal ecohydrology		✓						

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