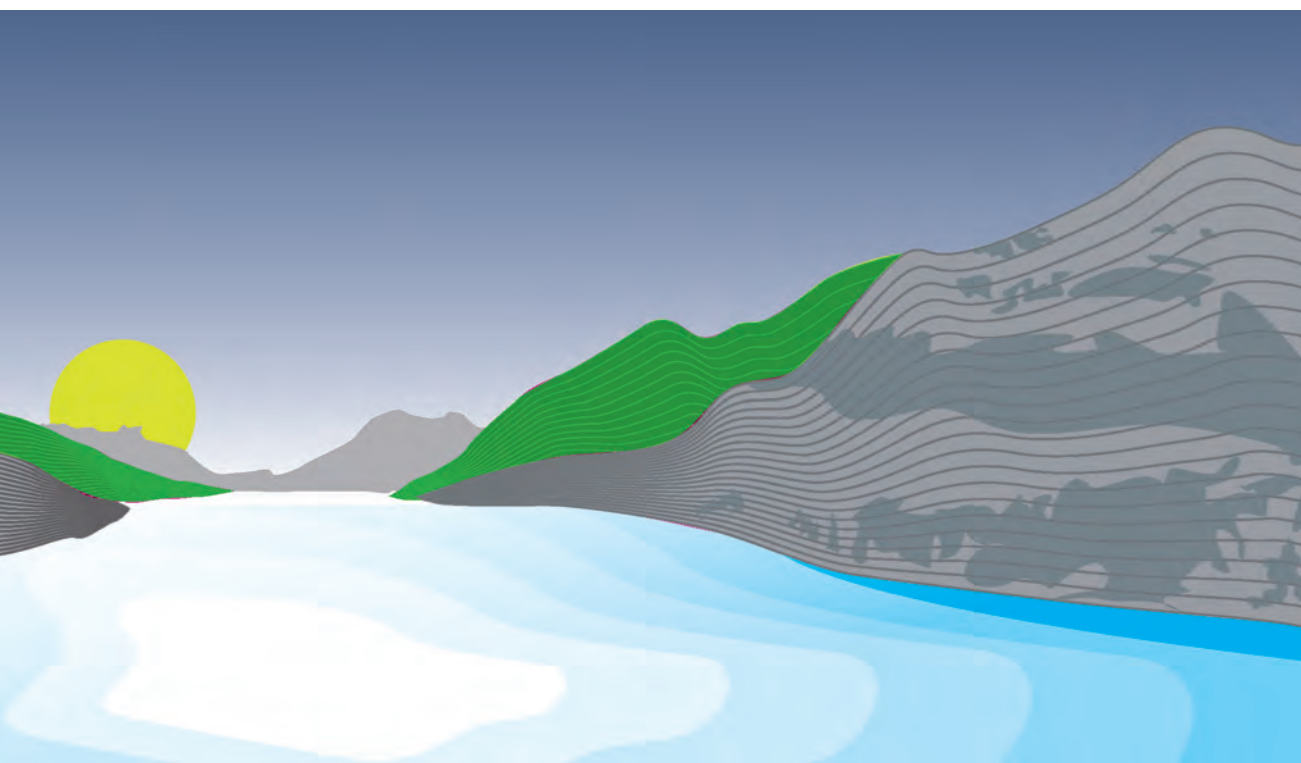




THE HANDBOOK ON WATER INFORMATION SYSTEMS

ADMINISTRATION, PROCESSING AND EXPLOITATION
OF WATER-RELATED DATA

March 2018



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FOREWORD

Water challenges are growing due to climate, demographic and socio-economic situations. These increased pressures potentially trigger conflicts between uses (irrigation, drinking, industry, hydropower, etc.) and between regions and countries. In addition, flood and drought events continue to devastate many parts of the world combined with an increasing threat to water ecosystems.

Whether at basin, national or transboundary level, easy access to information on the status and evolution of water resources and uses is one of the keys to successful water policy implementation. Water resource managers need to be able to get hold of reliable, up-to-date and relevant information for their activities related to regulation, planning, adaptation to climate change, risk management and public information.

Unfortunately, the necessary data and information are usually fragmented/incomplete/dispersed and heterogeneous, and accessing them is often difficult to organize for numerous reasons (e.g. multiplicity of data producers, inconsistency of data and information).

As a result, the data capital regularly produced by the various actors is underutilized, and the capacities for producing the information required for efficient water policy implementation are often very limited.

This situation may result in significant negative economic impacts as crucial planning decision may be taken with partial, insufficient and imprecise data and information. However, it can be improved with a minimum of political will, and an ad hoc action plan aiming firstly to rationalize existing information, fill the biggest gaps in data collection and make it easy to access and understand.

This handbook aims to provide decision-makers with strategy pointers for efficient water data management, and to guide any organization that would like to develop its capacities for producing, accessing, processing and making good use of the water-related data and information necessary for implementing an Integrated Water Resources Management policy.

This new work supplements the *Handbook for Integrated Water Resources Management in Basins*, published in March 2009 at the Fifth World Water Forum in Istanbul, and the *Handbook for Integrated Water Resources Management in Transboundary Basins of Rivers, Lakes and Aquifers*, published in March 2012 at the 6th World Water Forum in Marseille. Other complementary publications include the *Handbook for Management and Restoration of Aquatic Ecosystems in River and Lake Basins*, published in March 2015 at the 7th World Water Forum in Korea simultaneously with a guide entitled, *Water and Climate Change Adaptation in Transboundary Basins: Lessons Learned and Good Practices*. Another handbook, on "The participation of stakeholders and the civil society in the basins of rivers, lakes and aquifers" is being published simultaneously during the 8th World Water Forum in Brasilia.

We welcome your comments and contributions to this new handbook, which we consider to be a platform for sustainable development in its economic, social and environmental dimensions.

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TABLE OF ACRONYMS

AFB	French Agency for Biodiversity
AFD	French Development Agency
ANA	Autoridad Nacional del Agua
ANBO	African Network of Basin Organizations
AWRIS	Australian Water Resources Information System
BfG	German Federal Institute of Hydrology
BRGM	French “Bureau de Recherche Géologique et Minière”
CC	Climate Change
CCKP	Climate Change Knowledge Portal
CDL	Climate Data Library
CHRS	Center for Hydrometeorology and Remote Sensing
CMIP5	Coupled Model Intercomparison Project Phase 5
CMMS	Computerized Maintenance Management Systems
CORINE	COoRdinate INformation on the Environment
COTS	Commercial-Off-The-Shelf
CRIDA	Collaborative Risk Informed Decision Analysis
CRM	Customer Relationship Management
CSA	Canadian Space Agency
CUHASI	Consortium of Universities for the Advancement of Hydrologic Science, Inc.
DB	Data Base
DCP	Data Collection Platform
DHI	Institute for Water and Environment
DPs	Data Providers
DUS	Drought User Service
EEA	European Environment Agency
EMWIS	Euro-Mediterranean Information System on know-how in the Water Sector
ESA	European Space Agency
ETL	Extract-Transform-Load
EU	European Union
Eurostat	Statistical Office of the European Union
FAO	Food and Agriculture Organization
FD	Floods Directive
FDMT	Flood and Drought Management Tools
FOSS	Free and Open Source Software
GCOS	Global Climate Observing System
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GEOSS	Global Earth Observation System of Systems

GGMN	Global Groundwater Monitoring Network
GIS	Geographic Information Systems
GPRS	General Packet Radio Service
GRDC	Global Runoff Data Centre for Surface Runoff
GTN-R	Global Terrestrial Network for River Discharge
HIS	Hydrological Information System
HYDROLARE	International Centre on the Hydrology of Lakes and Reservoirs
HydroSOS	Hydrological Status and Outlook System
IAC	International Main Alert Centres
ICPDR	International Commission for the Protection of the Danube River
ICTs	Information and Communication Technologies
IHP	International Hydrological Programme
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute for Climate and Society
IMoMo	Innovative Technologies for Monitoring, Modelling and Managing Water
INAI	National Institute for Transparency, Access to Information and Protection of Personal Data
INBO	International Network of Basin Organizations
ICPR	International Commission for the Protection of the Rhine
IOWater	International Office for Water
IRWS	International Recommendations for Water Statistics
ISO	International Organization for Standardization
ISRBC	International Sava River Basin Commission
IT	Information Technology
IWA	International Water Association
IWRM	Integrated Water Resource Management
LEMA	Law on Water and Aquatic Environments
MEM	Ministry of Energy and Mines
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NHS	National Hydrological Services
NGOs	Non-Governmental Organizations
OGC	Open Geospatial Consortium
OMVS	Organization for the Development of the Senegal River
PACC	Plan for Adapting to Climate Change
PDF	Portable Document Format
QA/ QC	Quality Assurance / Quality Control
QGIS	Quantum Geographic Information System

RNDE	National Network of Water Data
RS	Remote Sensing
RS-TSA	Remote Sensing Time Series Analysis
SAGE	Water Development and Management Plan
SANDRE	French National Service for Water Data and Common Reference Frames Management
SAP	Strategic Action Programmes
SCADA	Supervisory Control and Data Acquisition
SDAGE	Master Plan for Water Development and Management
SDC	Swiss Agency for Development and Cooperation
SDG	Sustainable Development Goals
SEEA-Water	System of Environmental-Economic Accounts for Water
SEIS	Shared Environmental Information system
SNDE	National Master Plan on Water Data
SPI	Standardized Precipitation Index
CREPA	Regional Centre for Water Supply and Sanitation
SWOS	Satellite-based Wetland Observation Service
SWOT	Surface Water and Ocean Topography
TDA	Transboundary Diagnosis Analysis
UKSA	United Kingdom Space Agency
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNSC	United Nations Statistical Commission
UPHL	Local Hydrographic Planning Units
USGS	United States Geological Survey
UWWT	Urban Waste-Water Treatment.
EU	European Union
VIC	Variable Infiltration Capacity
WAP	Warning and Alarm Plan
WB	World Bank
WDMS	Web-Based Data Management System
WEDC	Water Engineering and Development Centre
WFD	Water Framework Directive
WFS	Web Feature Services
WHOS	WMO Hydrological Observing System
WHYCOS	WMO's World Hydrological Cycle Observing System
WIGOS	WMO Integrated Global Observing System

WINS		Water Information Network System
WIS		Water Information System
WMO		World Meteorological Organization
WMS		Web Map Service
WRA		Water Resources Assessment
WSP		Water Safety Plans
WUA		Water User Association
WWDI		World Water Data Initiative
W3C		World Wide Web Consortium

1 Introduction

1.1. Context

Water resources are under increasingly severe pressure from global drivers such as population growth, economic development models, and/or climate change. Although water is a finite resource, it has to serve more and more people and usages, while remaining available in quantity and quality for the environment.

The need for a reliable supply, the dependence of the energy and food sectors, and the need for ecosystem protection all require better governance of the resource.

Data is the "life blood" of an organization, for as it flows between systems, databases, processes, and departments, it carries with it the ability to make the organization smarter and more effective. The highest performing organizations pay close attention to the data asset, not as an afterthought but rather as a core component in defining, designing, and constructing their programmes. Data is essential to making well-informed decisions that guide and measure the achievement of the organizational strategy. Decision-makers at all levels need data: data sustain the continuous management of water resources.

How an organization uses and manages its data is just as important as the mechanisms used to bring them into the environment. Possessing the right data of appropriate quality enables an organization to perform processes well and determine which processes have the greatest impact. The highest performing organizations ensure that their data assets are accessible to the processes and individuals who need them, are of sufficient quality and timeliness, and are protected against misuse and abuse. [1]

1.2. How to use this handbook

This handbook aims to raise the awareness of water-sector decision-makers and guide those interested in developing their capacities for producing, accessing, processing and making good use of the water-related data and information necessary for implementing an Integrated Water Resources Management policy at basin, national, transboundary or regional level.

Drafted in partnership by representatives of INBO, UNESCO, WMO, Bureau of Meteorology/WWDI and IOWater, it includes many case studies provided by the partners and collected through INBO networks partners.

References to authors are indicated by [n°], and their names are presented in the list of references with the corresponding number.

Chapter 2 underlines why water data management is so important and makes general recommendations to avoid common mistakes.

Chapter 3 describes the five basic components and processes to be taken into consideration when organizing water-related information systems:

- **Water data governance** organization;
- **Data production processes;**
- **Integrated data management procedures** required to organize the exchange of comparable data produced by various institutions/organizations and to develop interoperability between the information systems of the institutions managing data;
- **Data processing aiming to transform the available datasets into useful information** to support decision-making processes and answer the needs of the various public sectors targeted;
- **Dissemination of information process** tools and procedures facilitating the dissemination of information.

Chapter 4 presents Water Information Systems (WIS) through their diverse uses, with some basic principles of implementation and several case studies illustrating how WIS are implemented for:

- ❶ IWRM and planning at basin and national levels;
- ❷ Climate change adaptation;
- ❸ Flood and drought management;
- ❹ Ecosystem protection;
- ❺ Sectorial water resource management (drinking water, irrigation, etc.);
- ❻ Reporting (SDG, WFD, etc.);
- ❼ Transboundary basin management.

Finally, the conclusion underlines some perspectives for development and innovation in this sector in the coming years.

2 Challenges and importance of good water data management

2.1 Challenges and domains of application

KEY POINTS:

- **“Knowledge is a pre-requisite to action”:** Good knowledge and easy access to data and information on the status and evolution of water resources and uses is one of the keys to a successful water policy: You can't manage what you don't measure and what you don't understand!
- **Integrated Water Resource Management (IWRM) should be based on validated data and information provided through integrated information systems** which must constitute an objective basis for discussion, negotiation, decision-making and assessment of the actions taken, as well as for coordinating financing from various funding sources.
- **Water resource managers should have regular access to reliable, up-to-date and relevant data** for operational management and for regulation, planning, risk management and public information.
- At local, national, transboundary, regional and global levels, **all organizations involved in water resource management should have access to data and information; however these needs will be different depending on the organization's role and level of action.**
- **Most of the necessary data is produced at national level by various organizations and is usually incomplete, dispersed and non-homogeneous.**
- A legislative/cooperation framework for organizing water data management is often lacking.
- Information users experience difficulties in identifying and in accessing the existing datasets: **only a small share of the datasets produced are used effectively.**
- **Most decision-makers do not have access to pertinent information for decision-making.**
- **Effort must and can be made to rationalize access and facilitate the use of existing datasets and information necessary for water management.**

2.1.1 Water-related data and information needs

In all countries, the development of coherent water resource management is fundamental to ensure sustainable socio-economic development.

Experience shows that **efficient water resource management cannot exist without efficient access to and management of the necessary data and information.** At local, national and transboundary levels, easy access and efficient use of the necessary data and information, e.g. on the status and evolution of water resources and uses, is one of the keys to successful water policy implementation [2].

The figure below underlines the various domains requiring access to water-related data.

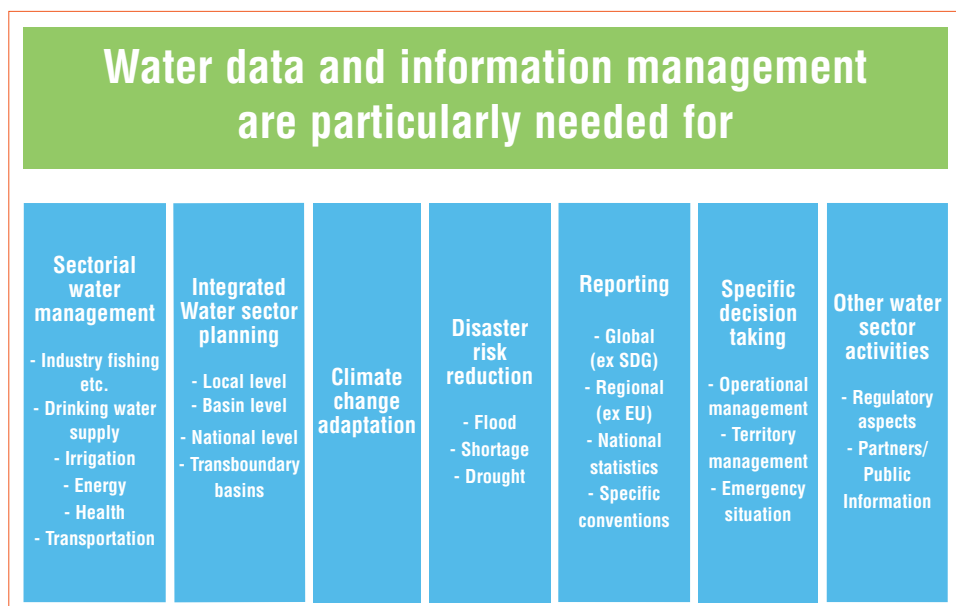


Figure 1: Different purposes for water data

However, in most countries, data collection processes are limited. When they are available, **existing datasets are usually fragmented, incomplete, dispersed and heterogeneous**. Organizations thus face difficulties in organizing data access, processing and optimal use, typically involving issues such as [2]:

- How to organise the production of new datasets and the enhancement of existing ones, in order to generate information and useful services for decision-making purposes and inform partners and the public?
- What are the datasets that already exist, in what form, and how can they be accessed in a flexible and efficient manner? How can be preserved from deterioration and loss?
- What are the best ways to manage the multiplicity of data producers and available formats as well as the issue of comparing datasets that are often incomplete, dispersed and of variable quality?
- What legislative / institutional frameworks exist to organize the sharing of data among partners as well as the processing and dissemination of the results?
- etc.

a) Immediate action is urgently needed but “knowledge is a pre-requisite to action”

Water energy and food shortages, pollution, waste, and ecosystem destruction - the situation in many countries is alarming and likely to get worse with climate and global change.

Immediate action is urgently needed, involving a global, integrated and coherent water resources policy that takes into account the legitimate needs of inhabitants while protecting aquatic and land ecosystems.

In this situation, “**knowledge is a pre-requisite to action**” and in the sector of water resource management, **lack of information is considered as one of the most limiting factors to making sound decisions**.

b) Water resource managers need regular access to reliable, up-to-date and relevant data and information adapted to their needs

The efficient management of water resources requires organizing the production and sharing of information to meet the expectations of stakeholders for the purposes of operational management, regulation, planning, monitoring, assessment, risk management and public information.

In order to achieve this, **water resource managers need regular access to reliable, up-to-date and relevant data.**

In many cases, individual institutions should possess their own information systems and manage their own data to produce the information they need for their missions.

For example, this is the case for:

- Preparing **legislative and normative** regulations;
- **Operating and maintaining key national infrastructure** assets;
- Managing the **water cadastre and water yearbooks**;
- **Calculating the water balance**;
- **Establishing environmental-economic accounts for water** (SEEA-Water- see box below);
- **Planning activities** (national and basin management plans, flood protection plan, prevention plans, etc.);
- **Granting licences and permits** for water abstraction, waste water discharge, and other water uses;
- **Determining pollution prevention** and environmental protection requirements and measures (protection areas for water resources, etc.);
- Organizing and **collecting water fees and fines** for uses such as concessions, water resource utilization, services provided, pollution taxes, etc.;
- **Monitoring investments and assessing activities** featuring in action plans;
- **Negotiating** the use of water resources **with other governments** and multinational organizations;
- Obtaining financial support for appropriate investments in the water sector;
- Involving the public in decision-making;
- etc.

Box 1: About the Environmental-Economic Accounts for Water (SEEA-Water)

The System of Environmental-Economic Accounts for Water (SEEA-Water) and the International Recommendations for Water Statistics (IRWS), adopted in 2007 and 2010 respectively by the United Nations Statistical Commission (UNSC), provide the **conceptual framework for monitoring progress towards water policy objectives** in countries and on an international scale. The SEEA aims at intertwining economy and the environmental components. The paramount ambition of the SEEA is to allow links to be made to economic series which impose first and foremost to harmonise the environmental data, with the likely simplifications that are required. **Does a certain type of activity which is environmentally sensitive play a particularly large role in international trade of the country or provide strategic resource (products, many employment opportunities)?** If common units can be used, the possibility of aggregation and the presentation of simple indicators are facilitated.

The SEEA is based upon building blocks that are:

- ① Physical flow accounts, that expresses flows between the environment and the economy (e.g. water abstractions / returns);
- ② System of National flow accounts;
- ③ Environmental assets, that can be expressed in monetary and physical units, depending on the category;
- ④ Valuation and environmental adjustments. Still very conceptual.

Also, as “**you can’t improve what you can’t measure**”, evaluation and performance measurement are also recommended for effective water governance. Benchmarking and bench learning can be systematized using “water governance indicators” that can help track weaknesses and foster better water governance.

Box 2: About governance and performance indicators for basin management

Performance indicators are an important tool to improve water governance. Two groups of indicators designed for basin organizations are to be considered:

- **Governance indicators**, which assess the organization of the institution compared to the main pillars of IWRM (political, institutional and organizational aspects, legal framework, funding mechanisms, participatory aspects, planning, information system and communication, capacity building);

- **Technical indicators** that evaluate programme results and characterize the evolution of the “field situation”. They are used to assess skills gained in terms of knowledge, water resources development and management, basin uses and users.

The set of indicators always depends on the context and should be interpreted according to the institutional structures specific to the basin (agreements, financing, functions, goals), hydrological conditions, progress in economic development, and the organization’s human resources. Thus, indicators can be used as guidance for water policy and provide advice on the effectiveness of IWRM implementation at the basin level.

This allows basin organization managers, staff and partners to ascertain what has been done and how it was done, and identify what fields need improving.

The data and information needs for water management are very broad, and it is clear that these needs depend on the type of activity and the level of action of each actor (different types of processing, different levels of aggregation). Examples:

- ① A flood-forecasting organization will not require the same data as a planning organization, even if they both work at national level;
- ② An organization preparing a water balance at national level will not need the same type of information and level of data aggregation as a dam-operating management organization, despite the fact that both need hydrological data.

2.1.2 Why is organizing access to water-related data so complex?

The reasons for insufficient and difficult access to water-related data are multiple and diverse. Some of these are briefly described below:

a) Multiple data producers on many topics

At local, national, transboundary and regional levels, a multitude of institutions produce and use the data needed for IWRM.

IWRM implementation requires data and information on many topics that are systematically produced by diverse institutions, e.g.:

- The equivalent of a water cadastre and an inventory of infrastructures are usually managed by the ministry in charge of water management and basin organizations;
- Meteorological data are mainly produced by Meteorological services;
- Hydrometric data are mainly produced by Hydrology services;
- Water quality data are usually produced by environmental organizations and health-related institutions;
- Ground water data are mainly produced by geological and mining institutions;
- Data on water uses for energy production are mainly produced by dam managers and the ministry in charge of the energy sector;

- Data on agricultural water uses are usually produced by irrigation system managers and the ministry in charge of agriculture;
- Statistics on population growth and urban characteristics are managed by statistics institutes;
- Topographic and geographic information is usually produced by geographic institutes;
- etc.

Moreover, these institutions generally operate at different levels (local, sub-national regional, national) and may have different in-house departments/services producing and using data.

b) The data is usually incomplete and dispersed

Due to the multiplicity of topics and producers, and the lack of agreement between these institutions regarding data exchange, the necessary information usually exists in a fragmented, dispersed form.

Moreover, **as each institution produces data for its own purposes** without necessarily considering the need for IWRM, existing datasets are generally **incomplete**, with time or geographic gaps.

Furthermore major gaps in time series or in geographical coverage are caused by the lack of means to ensure the regular check and maintenance of the monitoring equipment, the replacement of faulty parts or even the payment of salaries and fees to the staff, this results in many station being not operational.

c) Lack of homogeneity and comparability: each data producer manages its own data following its own procedures

As producers manage their own data following their own procedures, and as there are no rules adopted by the various partners to ensure the production of comparable data, existing data are usually **heterogeneous**, sometimes not comparable, and in many cases not digitized or available/accessible to partners and third parties.

d) Lack of traceability of existing datasets and difficulties to identify what exists

In many cases, data producers do not inform other institutions about their data production activities and **do not provide any characteristics (metadata) of the datasets produced**, such as information on: “how it is produced”, “how frequently”, “what are the access conditions”, “who to contact”, etc.

In many countries, there is no established place/tool where a potential final user of information can easily identify what data exist on a specific topic for a specific geographical area.

As a result, final users face significant difficulties and lose considerable time in identifying what exists, in learning how to access the existing datasets, and in checking if the datasets they can access actually correspond to their needs (lack of traceability due to the lack of metadata).

e) Lack of legislative and institutional frameworks organizing access and dissemination of water-related information

Accessing the necessary data and information on a basin is often difficult for both:

- Structural reasons - when there are no relevant agreements or protocols between the partner or institutions governing the process (or between countries for transboundary basins); and
- Technical reasons, linked to difficulties related to information collection, harmonization of data formats, definitions, analysis methods, frequency of data collection, density of monitoring networks and data processing.

In many cases, there is often no organization facilitating data and information exchange between institutions.

Moreover, the large number of public, semi-public and private organizations that produce and manage data often lack the means and guidance to exchange, gather, summarize and make efficient use of homogeneous and comparable data, following compatible procedures.

f) Data produced with public funds are not always freely accessible, and datasets are considered confidential

At national level, even in some countries that have signed the **Aarhus Convention**, organizations are often reluctant to make environmental information in their possession freely accessible.

In many cases, they judge that “information is power”, and act as if they were in “competition”, avoiding sharing any data, arguing either that such data are confidential or that they still need to control quality before making them available.

At transboundary and regional levels, a more general problem is the reluctance of national authorities to provide neighbouring countries with information as it is considered strategic for their development, particularly when located in an area with scarce resources: the economic value of water in terms of hydropower, agricultural irrigation, and navigation may increase this reluctance. Also, in some cases, datasets are transmitted too late to be useful.

In areas under conflict, authorities are reluctant to publish information on water resources, in particular geo-localization data, due to security risks.

Box 3: About the Aarhus Convention

The United Nations Economic Commission for Europe (UNECE) Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters adopted on 25 June 1998 establishes a number of rights of the public (individuals and their associations) with regard to the environment.

The Convention provides among others for **the right of everyone to receive environmental information that is held by public authorities**. This can include information on **the state of the environment**, but also on **policies or measures taken**, or on the **state of human health and safety** where this can be affected by the state of the environment. Applicants are entitled to obtain this information within **one month** of the request and without having to say why they require it. In addition, **public authorities are obliged, under the Convention, to actively disseminate environmental information in their possession**.



Figure 2: Map of parties and signatories to the Aarhus convention (Source: www.unece.org)

g) Lack of financial and human resources

Some countries do not possess suitable water information systems, nor the expertise or capacity to build systems and manage data. This is why it is important for international and specialized agencies to continue providing support for self-management of water-related data.

Box 4: Examples of cooperation programmes supporting data management

The transition to better data management can be fostered by inclusive and participatory platforms, such as the **UNESCO** International Hydrological Programme's Water Information Network System (IHP-WINS), by which countries remain responsible for their own data but receive support in managing and storing data, writing metadata, etc. This is particularly important for low- to middle-income countries that do not have the resources (financial, human, technical) to set up data management systems, as well as small countries, such as small island developing states (SIDS).

On its part, the **WMO** supports countries in their hydrological monitoring efforts through programmes and projects such as WHYCOS (World Hydrological Cycle Observing System), MCH (Meteorological, Climatological and Hydrological Database Management System) and WHOS (WMO Hydrological Observing System), in addition to providing regulatory material and a quality management framework. These activities are deployed under the umbrella of the newly established "Global Hydrometry Support Facility (WMO HydroHub)", which aims to improve the effectiveness and sustainability of monitoring the hydrological cycle through innovative approaches. WMO Congress, by adopting the Resolution 25 (Cg-XIII) Exchange of Hydrological Data and Products reaffirmed the commitment of the international community to broadening and enhancing, whenever possible, the free and unrestricted international exchange of hydrological data and products, in consonance with the requirements for WMO's scientific and technical programmes; in particular it stipulates to provide on a free and unrestricted basis those hydrological data and products which are necessary for the provision of services in support of the protection of life and property and for the well-being of all peoples.

In addition, many bilateral and decentralized cooperation programmes related to water resource management also include components to reinforce data management procedures at national and/or basin level, for example, projects coordinated by **IOWater** thanks to financial support from multilateral, national and/or basin agencies (case of cooperation programme supported by the French water basin agencies).

2.1.3 Consequences of the lack of easy access to data and information necessary for water management

a) Only a small share of the existing datasets are used efficiently

Information users encounter many difficulties in identifying what datasets already exist and how to access them. As a consequence, only a small share of the information already produced is used efficiently. This is due to:

- **The multiplicity of topics**, data producers, and existing data sources;
- **The lack of tools and procedures** to easily identify the existing data;
- **The lack of efficient procedures** and an institutionalized exchange of data that could be considered of common interest to various institutions.

As a result, existing data is not used effectively, and the performance of investments in data production is low.



Figure 3: Lack of access to data and information for the public and decision-makers

b) Low efficiency and duplication of work in data management / processing / dissemination

Due to the lack of adapted tools, some organizations spend excessive time on activities that could be automated or at least semi-automated.

For example, this is the case in:

- Organizations that spend significant time and money on data source identification when tools such as “catalogues of data sources” could allow the use of an online specialized search engine;
- Organizations that spend considerable time every day communicating data to partners by telephone instead of by automatic data exchange;
- Organizations that spend considerable time every day preparing tables and charts, which could be generated automatically or semi-automatically, whether for internal use or to answer requests from partners.

Moreover, the lack of co-ordination between the various administrations working in the water sector results in a waste of resources with considerable duplication of work and data management.

For example, this happens when:

- The same information is produced several times by various institutions without cross-consultation, with as a final result, the production of non-coherent information;
- The same data, already computerized by one organization, is digitally captured and updated by other institutions again and again, thus duplicating the work of data capturing, increasing the risk of mistakes and the need for data validation, and creating a multitude of similar data sources.

c) Limited level of quality control on existing datasets due to the lack of possibilities to cross-check data from various sources

When various data producers generate the same type of data on the same object, they should have the internal possibility to cross-check their data with data from other institutions in order to control the coherence of their data.

For example, this is the case when various organizations involved in quantitative management of the same river cannot easily exchange data for cross-checking and quality control.

d) Decision-makers do not have access to pertinent information for decision-making

It is well known that decision-makers cannot make good decisions if they do not possess the necessary information describing the existing situation, the objectives, and the various options to reach those objectives.

In water management sectors, whether for operational short-term water management or medium- and long-term purposes, it is rare that all of the necessary data already exist. However, in many cases, due to the incapacity to access existing data and process it on time to produce pertinent information, the result is poorly informed decisions.

The financial and environmental impacts of these decisions can be very high, and include the risks to human health or life when dealing with risk management (floods, dam safety, etc.).

e) The public cannot effectively participate in decision-making processes as required by IWRM principles

One of the IWRM principles is that representatives of civil society should have the possibility to participate in decision-making processes related to water management and that suitable information should be made available to the public in order to facilitate this participation.

In many cases, the necessary data are not available and the information is not produced or disseminated. As a result, the data are not available to set off the discussion and consensus-reaching processes, and ensure that decisions are socially and economically acceptable.

f) Transboundary water management cooperation can be limited due to a lack of information exchange

The importance of facilitating access to data and exchanging information on transboundary water is frequently highlighted.

For example, this is the case of the UNECE Water Convention, which includes provisions on the exchange and protection of information, as well as public access to information:

“Exchange of information – including on pollution caused by accidents, on infrastructure projects that could affect downstream countries, on extreme events (floods and droughts) as well as on operations such as for hydropower, navigation and irrigation – is vital to building trust and a shared vision among riparian countries”. In this context, a number of key policies on the “free and unrestricted” exchange of hydrological data and products are being promoted by WMO and UNESCO [3].

Moreover, there is also a consensus among experts that international watercourse agreements need to be more concrete in relation to data sharing. A study [4] entitled, “Greater exchange, greater ambiguity: Water resources data and information exchange in transboundary water treaties” indicates that of the 287 treaties analyzed in this study, only 37% (106) provide for direct data and information exchange mechanisms.

2.1.4 Conclusion: significant need to develop data production, rationalize access to existing datasets and information, and enhance their visualization and use

Data hoarding and inefficient coordination hamper efforts to solve the increasingly acute problem of access to water [5]. It is vital that organizations grasp the problem and develop water information systems as a solution to better data sharing for water resources management. They need to create efficient and integrative networks, to find ways in which different sectors could benefit each other.

Data management is a long-term project. Solutions (e.g. information systems) for the management, collection, storage and processing of data should be sustainable because they are durable and hard to change. Thus, foresight and investment are required. Clean data should be the base for ensuring quality information, while visualization solutions can enhance the impact and understanding of data.

Effective management of the world's water resources requires credible and reliable data and information regarding the state of the resource, and how it changes as a result of resource use and development, land use practices, and climate change.

Without forgetting the need to reinforce the monitoring and data collection processes, it appears that **the capital of data already regularly produced by the various institutions directly involved in water management and other institutions (e.g. those producing geographic, statistic, remote-sensing information), is often inefficiently used and underutilized.**

A significant effort must and can be made to rationalize existing datasets and information, make them easy to access and understand, and make them available to final users, following rules agreed by the various stakeholders. [6]

Experience shows that, when managed effectively, data issues can provide a framework for developing new patterns of cooperation.

Decision-makers and member states will only understand the importance of data and manage them effectively if it benefits their policy-making and the implementation of water resources management. Indeed, it is essential to have the ability to track, audit and report on water uses, issues, risks, etc.

However, in many cases today, simply collecting data on water management is impossible, not to mention analyzing it in any meaningful way [7]. As a result, there is an unavoidable need in the water-sector for good data on the entire water cycle for better management of water resources

Establishing facts is key to improving process understanding, model calibration and validation, and ultimately enabling informed decisions. Water facts are built through hydrological

monitoring, ranging from data collection to products and services. Data are the basic dialogue tool between stakeholders and the measure of the success of decisions and compliance with international treaties.

2.2 Selecting the right water data management tools – avoiding common mistakes

This chapter presents examples of criteria to be considered when selecting the tools to be used for water management systems.

a) Introduction

Getting water information right is a major challenge, requiring careful planning, judicious investment and diligent execution of strategy, including investment in the right water data management tools. These tools are vital for a wide range of water data management tasks, including data curation and information service delivery to end users. These systems represent the foundations of most water data management workflows. As such, the capability and performance of the tools used for data management largely determine the effectiveness of water data policy, planning, management and operations arrangements. They also affect strongly the value of water data itself as they affect how information is utilized and by whom. For these reasons, it is essential to implement effective tools and procedures.

To avoid common mistakes when selecting and implementing the tools, there are four key attributes to consider. These relate to functionality, maintainability, spatial enablement and dependability.

b) Functionality

Functionality comprises two aspects: internally facing and externally facing. The first relates to the numerous water data curation tasks that need to be undertaken using the system. The second relates to the water information services generated by the system for the benefit of water stakeholders.

Data management tools are used for many different data curation tasks, including data importing, quality control, editing, transformation, analysis, archiving and distribution. It is ideal to formalize as many of these tasks as possible as repeatable business processes, as this will enhance the efficiency and reliability of the tasks. Before selecting, developing or updating the data management tools, it is therefore beneficial to have a clearly documented set of user requirements, with three key characteristics:

- ① The requirements encompass all of the anticipated water data curation workflows;
- ② They are developed with input and approval of the specialist staff responsible for water data curation, and
- ③ They are informed by assessments of what is practically possible given available budget allocations and project timelines. The best way to make such an assessment is to examine carefully what other water data management agencies have accomplished with known resources and within set timelines.

The utility value of water data is increased when it is incorporated into water information services. Examples are those focused on spatio-temporal variations in river discharge, trends in groundwater levels, and extractions and fluctuations in reservoir storage volumes. Water forecasting services are another type of water information service, combining observed water data with predictive water models to provide users with forecasts, outlooks and scenarios for the future. Developing tools that deliver these types of services effectively enhances the ability of water stakeholders, particularly those without expertise in data handling, to interpret water data and to incorporate it into their decision-making processes.

c) Maintainability

Water data management tools are complex and costly to maintain. When designing a new one or re-factoring an existing one, it is recommended that due regard be given to the underlying system design, as this will determine its maintainability and total cost of ownership [10].

Water data management tools span a range between three poles. “Commercial-Off-The-Shelf (COTS)” solutions are generic systems provided by vendors that are suited to common, repeatable tasks. Business accounting software, Geographic Information Systems (GIS) and word processing software are good examples of COTS solutions. At the other end of the spectrum, “bespoke” solutions entail the unique ground-up development of a system. Although bespoke systems may use COTS products as sub-components, they are nevertheless a highly customized and unique instance of software. Many older tools were almost wholly bespoke solutions but nowadays the available COTS solutions can deliver most of the functions required.

For water data agencies with limited IT development and support capacity, the COTS path is preferable to a bespoke approach. It reduces development risk, the time required to implement a solution, and increases ongoing maintainability. The cost may not necessarily be lower, but it is predictable, as COTS solutions require a known initial financial outlay to install and commission, followed by a recurrent support licensing fee.

Free and Open Source Software (FOSS) initiatives offer an alternative to COTS approaches knowing that “Free and Open Source Software” refers to software which has been made available under a free software license with the rights to run the program for any purpose, to study how the program works, to adapt it, and to redistribute copies, including modifications. Choosing a water information system represents a difficult decision for investors. Indeed, the fact that various software vendors do not invest in cross-platform software development does not mean that migration to a new platform is not possible. Similarly, COTS does not necessarily mean vendor-lock-in, while FOSS does not necessarily mean vendor independence and open standards.

As a result, several questions should be answered before opting for one of the possible solutions.

- ❶ Regarding the ease of integration: does the system need to be flexible and have ease of integration?
- ❷ On flexibility and extension: Do you predict a need to extend internal components or extend the core product?
- ❸ On supportability: do you have internal IT operations that need to support the solution? Do you have skills in-house to support and diagnose?
- ❹ Finally, on cost: does it make sense to buy a product versus the support costs of FOSS?

The Free and Open Source Software (FOSS) model provides interesting tools and processes with which women and men can create, exchange, share and exploit software and knowledge efficiently and effectively in relation to water resources management. FOSS has the potential to play an important role as a practical instrument for development as its free and open aspirations make it a natural component of development efforts in the context of the SDGs.

There is an absolute need to remove restrictions in order to disseminate data and information to water stakeholders and policy-makers. Promoting ‘openness’ in content, technology, and processes through awareness-raising, policy formulation and capacity-building is trusted as a tool to broaden access to data, information and knowledge.

Effective access to data, in a responsible and efficient manner, is required to take full advantage of the new opportunities and benefits offered by ICTs [11]. The accessibility of research data has become an important condition for the good stewardship of public investment in factual information, the creation of strong value chains of innovation, and the enhancement of value from international cooperation. More specifically, improved access to, and sharing of, data reinforces and promotes open research, encourages diverse analysis and opinion, supports studies on data collection methods and measurement, facilitates the education of new researchers, and permits the combination of multiple sources to create new data sets. It is crucial to foster the democratization of such systems, as they participate in closing the existing gap between North and South in terms of access to data [12].

d) Spatial enablement

Spatial enablement is the process of attaching salient geographic information to data in order to aid the discovery, querying, interpretation, visualization and downloading of that data. This is vital in the case of water data because they almost always possess spatial attributes that are relevant to their meaning. For instance, river discharge is measured at a point on a river but represents the accumulation of all runoff generated in the river network upstream of the measurement point. As such, river discharge data cannot be properly interpreted without proper characterization of the upslope contributing area.

Geographic boundaries for different kinds of management areas are also very important for providing spatial context for water data. Examples include boundaries for states, provinces, cities, towns, basins, irrigation districts, farming regions and conservation areas. Such geographic boundary information is commonly used to derive spatial averages and totals of water data values so that they have greater meaning for water stakeholders.

Spatial enablement of water data involves storing salient spatial information layers in a Geographic Information System (GIS), along with the location coordinates for water data measurements. In the simplest case, these spatial information layers will be map representations that are simply used for reporting. However, much greater benefit can be derived by building up a spatial information model for hydrological features in the landscape, sometimes referred to as a 'hydrological geospatial fabric' [13]. A hydrological geospatial fabric provides an objective basis for catchment and groundwater system delineation. It also supports a range of hydrological modelling tasks such as the routing of flows through river networks and the exchange of water between surface water and groundwater systems. Groundwater data and information management requires also the capabilities to represent effectively data that have a three dimensional reference

e) Dependability

Water stakeholders depend on the continuous availability of WIS. However, the continuous availability of any information system is difficult to accomplish for a variety of reasons, such as service interruptions during upgrades, hardware failure or malicious activity. The most effective mitigation for such service risks is to implement multiple instances of the tools for data management; ideally four separate instances across production, failover, pre-production and development systems. Risk is further reduced by applying specific levels of security, physical separation and access controls to each instance. Maintaining these four separate instances provides dependability through secure operations and an authentic and relatively risk-free environment for system development and testing.

Physical security arrangements, backups and access control to system codes and associated files are vital safeguards against deliberate or accidental damage to the system. Other basic safeguards that can be applied include the mandatory use of strong passwords, mandatory updating of passwords every few months, and the immediate installation of security patches when made available by software vendors. Continuous monitoring of system performance is also advisable.

f) Summary

In summary, water data management systems are the foundation of most water data management processes. These systems require substantial investment and are a major determinant of the effectiveness of any water data management programme. Hence, it is important to give careful regard to their design and operation.

These systems will be most effective when implemented with a focus on functionality, maintainability, spatial enablement and dependability. Key goals should be: to commence with carefully prepared user requirements informed by internal and external stakeholder preferences; to link water data assets to a hydrological geospatial fabric; and to implement multiple instances of the system for security.

3 MAIN COMPONENTS/PROCESSES RELATED TO WATER DATA MANAGEMENT

MAIN KEY POINTS:

- Five main components/processes should be considered: governance, data production, integrated data management, data processing and efficient use, and information dissemination.
- Governance: In many cases the implementation of an efficient shared water information system requires inter-institutional cooperation and a water data policy that organizes in particular the sharing of responsibilities between institutions. This cannot be established without a strong political will, considering that investments in data sharing and information systems development generally demonstrate a very positive return on investment.
- Data production: This should be organized considering the needs, and involve all partners through a combination of traditional monitoring procedures and remote-sensing data that could be completed with crowd-sourcing data.
- Integrated data management: When working at regional, national or basin level, the introduction of a water information system or data exchange mechanism never starts from scratch since numerous institutions will already produce, manage, exchange and use relevant data. An ad hoc strategy relying on a diagnosis of the existing situation is required, along with a common language for insuring the comparability of data, and procedures for developing interoperability between existing information systems.
- Data processing: Many tools are available for processing and transforming raw datasets into information that is easy to access and understand by final users thanks to ad hoc visualization modes and ad hoc communication support.
- Information dissemination: Various channels and digital tools (portals, smartphone apps, social networks, etc.) are available and can be exploited in the frame of an ad hoc communication strategy.

When developing a water information system, particular attention should be paid to each of the five main following components/processes [2]:

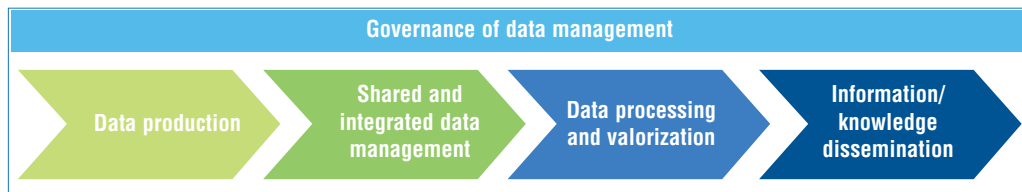


Figure 4: Five main components/processes to consider

3.1 Water data governance

KEY POINTS

- Political willingness with a high commitment is a key element to develop **inter-institutional cooperation on data management** and establish a **water data policy (management governance)**.
- Governance includes a combination of legislative texts (law, decree, etc.); documents featuring strategies and procedures for inter-institutional coordination; organization of a steering committee and specific working groups.
- Investments in data sharing and information systems development generally demonstrate **a very positive return on investment**.

3.1.1 Main principles of water data governance

Water resource management requires having access to various datasets on many topics which, in all countries, are always produced/ managed/ processed by many different institutions.

Efficient access to these datasets requires establishing good **inter-institutional cooperation on data management** and developing a **water data policy (management governance)** in order to reinforce synergies by sharing roles and responsibilities between the actors for water data production, management, processing and use.

Considering the diverse legislative and institutional frameworks encountered in different countries, various options can be implemented to organize this governance. In many cases, it will include a combination of:

- Legislative texts (law, decree, etc.);
- Documents featuring strategies and procedures for inter-institutional coordination;
- Organization of a steering committee and specific working groups.

Legislative text

If the legislation is not adapted to facilitate inter-institutional cooperation, the willingness of decision-makers alone may not be sufficient, considering that in many cases they may exceed their obligations.

Therefore, the legislative text organizing cooperation in the water sector should include chapters or specific decrees:

- Facilitating data sharing between institutions;
- Establishing the data management and use, ownership principles and on commercial use by third parties;
- Presenting the national water information system as a fundamental tool to support the water policy;
- Specifying the role of the main institutions;
- Stimulating the partnership, and organizing the governance and financing.

Strategies and procedures for inter-institutional coordination [6]

At national level, prior to the adoption of a legislative text, the political will to organize the sharing and rational production and use of water-related data between institutions can also be implemented in a strategic document specifying the country's water data policy.

At transboundary level, exchange protocols can be implemented between countries and/or between the country and the transboundary basin organization.

In all cases, it is essential that all decision-makers recognize the importance of having access to adequate information to efficiently address water management issues, remembering that:

- ① Good information is crucial for all integrated water resources management decisions.
- ② Poor information creates uncertainty and leads to poor operational management and policy decisions and inefficient investment decisions.

Therefore, the water information system must be seen by all as a **fundamental tool to support water policy** (whether at local, national, transboundary or global level).

Indeed, in many cases, decision-makers do not immediately see the interest of investing in water data management. This is why it is important **to develop an exchange of experiences and use every opportunity to demonstrate the benefits that each institution can derive** from working together on a shared and integrated water information system.

Effectively mobilizing partners involves:

- ① Clarifying the role and missions of each participant in a framework of well-defined organizational structures;
- ② Applying “project management” and “quality control” methodologies to all information system components and procedures;
- ③ Defining internal organization rules for data production/sharing/dissemination.

Case study 1: France/Legislation related to the national Water Information System in France [14]

After an initial phase of development, which started in 1992 under the name of the National Network of Water Data (RNDE), and after various transitory decrees, the concept of the present national WIS was established by the Act on water and aquatic environments (LEMA) of 30 December 2006, L213-2.

In its article 88, the LEMA specifies that the “Office national de l’eau et des milieux aquatiques” ONEMA (now integrated into AFB), which is a state administrative institution, will among others:

- “... ensure the implementation and technical coordination of an information system for the collection, conservation and dissemination of data on water, aquatic environments, their uses and distribution of water and sanitation utilities. Local authorities or their groupings are associated with their application to the constitution of this information system”.

Decree n°2007-443 related to the ONEMA specifies in its article 1 that: “in relation with the information system, the AFB collects the data and indicators related to water, aquatic environments and their use and about water supply and sanitation utilities. It defines the technical frame of reference to enable interoperability of its components of collection, conservation and dissemination, and makes them available in conditions fixed by Decree”.

Decree n° 2009-1543 signed by the Prime Minister specifies that:

- The technical frame of reference mentioned in the decree n°2007-443 and developed by the “Office national de l’eau et des milieux aquatiques”, consists of a **national master plan on water data (SNDE)** with annexed technical documents;
- “Any person wishing to participate in the establishment of the information system on water must comply with the technical frame of reference.”

This SNDE specifies:

- The objectives, scope and modalities of governance;
- Collection procedures, conservation and dissemination of data and indicators;
- The terms of implementation of these procedures;
- The modalities for the preparation of methodologies and the frame of reference of data and services that these procedures must follow to ensure their interoperability;
- Detailed rules for the exchange of data with other information systems not fully included in the perimeter of the water information system.

Once the general framework for cooperation has been established, a win-win relationship between the partners needs to be put in place to ensure the partners' sustainable participation. For example, a partner could benefit from the system by:

- Obtaining access to data produced by other partners;
- Getting technical assistance to develop its own information system;
- Getting help as the data producer to ensure quality control of its datasets;
- Building capacities for its human resources.

At a later stage, the development of specific data exchange scenarios can be envisaged on a case-by-case basis. These scenarios, once agreed by the partners, can then be tailored to each data exchange process. These should specify, among other things:

- Who exchanges what data with whom;
- For what purpose;
- Following what procedure (format, frequency, etc.).

With a view to partners' long-term participation, these scenarios should contribute to establishing an environment of trust between the partners by:

- Respecting the role of each actor that owns data, involving each partner in the definition of the scenario from the beginning;
- Respecting the level of confidentiality defined by each producer, not using or disseminating data or information without their agreement.

Steering committee and specific working groups

At both national and transboundary levels, the efficient sharing and processing of comparable data produced by various agencies requires clarifying the roles of each partner. This ensures regular participation and efficient coordination to develop the various components of the system.

An ad-hoc operational framework should therefore be established for the water data management, taking into consideration the main water issues and the institutional context.

In many cases, a three-level governance system is appropriate, including:

- A steering committee to define the priorities and guide the information system development;
- A technical unit to lead and ensure technical coordination of the system;
- A network of partners that produce, manage and use data and that have opportunities to participate in working groups established to develop the system.

The main mission of this organizational framework should be to develop capacities for production, enhancement and sharing of comparable and quality information that is useful for sustainable water resources management.

Depending on its action level (regional/national/basin), it should be in a position to support all policies and actions likely to affect water resources management, by:

- ① Organizing collaboration for better water data sharing between institutions;
- ② Developing and adopting common procedures validated by national organizations to describe existing data sets (metadata) and produce comparable data and information;
- ③ Organizing development of procedures and technical infrastructures for the networking of data and information identification services, consultation and downloading, according to the access rights agreed with the partners;
- ④ Organizing production, interpretation and dissemination of the information needed for water data management at national, basin and local levels;
- ⑤ Developing human resources capacities, in order to improve the quality and efficiency of the water data management.

Case study 2: Challenges/role of governance in the case of national water information systems in the Mediterranean region [15]

During a workshop organized in 2017 in the frame of EMWIS data management platform development, it was considered that the key elements for effective national water data governance are:

- Confirming **high-level political commitment** to enhance cross-sectoral coordination, data sharing and joint information production for better water management. This political willingness is a key element to implement the governance structure necessary for developing and managing a water information system;
- Positioning the importance of a water information system for efficient water management within the **national water legislative framework**, including sectoral coordination and definition of responsibilities with regard to cooperation and information sharing;
- **Formalizing the governance mechanism** with a multi-stakeholder agreement, a Memorandum of Understanding or a regulatory text;
- Ensuring broad agreement and commitment from all stakeholders by looking for **win-win solutions** at all stages of development as well as in the operation of the system;
- Defining a **multi-level governance structure**, including strategic coordination, technical coordination and operational coordination from national to local level;
- Ensuring human and financial resources for the operation of the governance mechanism and the implementation of the water information system.

The **strategic governance body** is usually chaired by the minister in charge of water and brings together all ministries and agencies concerned by the water sector (environment, health, agriculture, industry, housing, finance, international cooperation), including representatives of river basin committees. It is responsible for:

- Defining priorities for the development of the WIS in order to respond to policy challenges;
- Ensuring that the WIS is integrated into and contributes to cross-sectoral policy frameworks, such as climate change mitigation and adaptation strategy, administrative modernization, open public data, etc.;
- Initiating when necessary new regulations enabling further development of the WIS, such as financing regulations; revising the role and competencies of public agencies to avoid overlaps while ensuring data production and sharing;
- Reviewing WIS implementation progress and operation of the WIS components.

The **technical governance body** is chaired by the institution formally responsible for the water information system. It includes the technical department of the different ministries and agencies involved as well as scientific and research institutions and river basin agencies or regional entities in charge of water management. It is in charge of:

- Ensuring communication among all stakeholders, including the user community;
- Ensuring that the needs of all stakeholders are sufficiently addressed;
- Setting up and running thematic working groups in charge of developing data exchange standards, reference data frameworks, guidance documents, and terms of references for the implementation of the system;
- Supervising WIS implementation and monitoring progress;
- Coordinating reporting to the strategic governance body;
- Operating the Water Information System and validating its results.

The **local or river basin coordination body** is usually chaired by the river basin organization or a regional entity in charge of water resources. It has the key role of data collection on the field and defining local operational needs in relation to water resources management as well as sectoral needs from local communities, e.g. agricultural sector, municipalities, industry,

3.1.2 About financing of WIS

Investments in the water sector are capital-intensive: building large infrastructures on river basin scale, or for inter-basin transfers, large water mains, treatment and sewerage plants, including distribution, irrigation, drainage and wastewater collection networks, represents major initial unit costs which need to be staggered over time, and which realistically can only be paid off over a very long period of several decades.

Investments need to be scheduled for the medium and long terms, and target objectives and all types of necessary resources must be specified in the water planning and management master plans, based on realistic data and information.

Compared to water sector investments, investments in data production and information management are substantially smaller, and can generate a very positive impact on decision-making in relation to investment allocation.

Moreover, in the longer run, efficient information systems might also become indispensable for organizing the collection of fees and taxes on water abstraction and discharges of pollutants, such as those recommended in IWRM implementation principles.

This is why investments in data sharing and information systems development generally demonstrate **a very positive return on investment**.

However, these must be planned from the beginning to ensure the system's sustainability. [6]

Financing challenges

When defining the financing of a water data management system, it is important to consider both the overall approach and each individual cost item for progressive system development. This should cover:

- The implementation costs: studies (feasibility, detailed specification), system development (software, equipment), training, data acquisition, reinforcing the monitoring network, developing the interfaces for data exchanges, etc;
- The operational costs: governance structures (including working groups), network and system maintenance, telecommunication, communication and dissemination of final information products, data acquisition, technical support to stakeholders;
- The system evolution costs: studies, implementation and training.

These three levels of financing are important to ensure the long-term sustainability of the water information system. Most water information systems projects focus on the initial implementation cost without anticipating the financing needs of the following steps, resulting in a system that does not provide the expected information and thus slows down the momentum for further developments. The financing requirements for the operation of the system should be defined by the Technical Governance Body during the implementation phase to give sufficient time to the Strategic Governance Body to mobilize the necessary funding schemes.

A cost-benefit analysis of environmental data management and derived information products and services (e.g. indicators, map, online applications, dashboards, bulletins) is always difficult to assess.

Maximizing the different stakeholders' use of data should be a core objective of a WIS. As the cost of data production does not directly depend on the number of uses, the justification for financing it will be easier.

Another approach consists in comparing data management costs, data collection costs (e.g. monitoring networks, water quality analysis) and water infrastructure costs. In this way, it is possible to provide decision-makers with ratios that directly link data management with investment planning and assessment.

3.2 Data production

KEY POINTS [16]

- The regular production of data related to the status and evolution of water resources' quantitative/qualitative aspects and uses is required for implementing a successful water policy.
- Data are generally produced by in situ monitoring stations, survey reports, etc. and increasingly supplemented by remote-sensing data and/or crowd-sourcing data.

To ensure successful water management, water resource managers need to be able to get hold of reliable, up-to-date and relevant data and information when they need it and in a form that they can use.

Within each country, the necessary datasets are produced through various data collection processes managed by numerous institutions, and generally organized through:

- Monitoring programmes established at national, basin and local/organization levels;
- Self-monitoring processes (e.g. by individual industries relating to discharges);
- Surveys / inventories / inspections carried out by statistical services or administrative services involved in the management of water resources (basin organizations, municipal services, etc.);
- Declarations related to administrative procedures: authorizations / permits for sampling and discharges, declaration for construction of water works;
- Studies and simulations (impact studies, technical study of works, etc.).

Box 5: Inventory of data collection processes

As each organization generally produces its own datasets following its own mandates and objectives, inventory and characterization of the data collection processes is recommended depending on the case at basin, national or transboundary level, in order to avoid gaps and duplications of activities, and taking into account the final needs.

As an example, in France, an inventory of data collection processes was organized as part of the SANDRE and is presented online with a list of **1,473 data collection “measures” contributing to water-related data production.**

This kind of inventory, established at basin and national levels, helps to organize the sharing of responsibility between the various data producers and identify any gaps. This leads to the validation of an action plan to produce the missing data as part of the basin and national data management plans.

Monitoring programmes in many cases rely on data production processes using traditional **monitoring stations (in situ)**. However, in response to the lack of data and thanks to new drone/aerial/satellite and communication tools, traditional collection is now increasingly supplemented by **Remote Sensing (RS)** and **crowd sourcing data**.

3.2.1 About in situ monitoring

In situ monitoring is the main way to really understand hydrodynamic processes and the only one to collect data directly from aquatic systems. In spite of well-known drawbacks (operation and maintenance costs, especially for remote areas, requirement of expertise and experience,

poor geographical representativeness) it offers the possibility of collecting high-quality, homogeneous, standardized measurements that will be required on a very long-term basis. Furthermore, with emerging remote-sensing technologies and citizen observations, high-quality in situ data will remain essential for ground truthing, calibration and validation of measurements using other methods.

Given that many manuals and guides already exist on organizing water-related monitoring programs, this chapter simply underlines some basic principles.

Firstly, designing a monitoring programme involves deciding what to monitor, where and when. The answers to these questions depend first and foremost on the purpose of the monitoring. The first step before designing the number and location of the monitoring points constituting a network is therefore to clearly identify the purpose, or purposes, for which the monitoring information is needed.

Monitoring stations are generally grouped into monitoring networks, so that a monitoring network can be defined as *a set of strategically located measurement devices that collect data of interest about a water system at a given temporal scale*. [18]

a) About meteorological networks

Meteorological data needs to be collected over many years, even decades, in order to produce reliable statistics. Building a functional and exhaustive meteorological database for accurate models requires high-quality observations of a variety of relevant measurements. Modelling can then be used to understand past, present, and potential future climate conditions. [19]

Box 6 : About the network of the National Meteorological and Hydrological Services (NMHSs) [21]

WMO coordinates a network of the National Meteorological and Hydrological Services (NMHSs) of its 191 Members which operate the:

① **WMO Global Integrated Observing System (WIGOS)** enables the collection of data from 17 satellites, hundreds of ocean buoys, thousands of aircrafts and ships and nearly 10,000 land-based stations;

② **WMO Global Telecommunication System (GTS)** is composed of a dedicated network of surface and satellite-based telecommunication links and centres operated around the clock all year round. It interconnects all NMHSs for collection and distribution of all meteorological and related data, forecasts and alerts, including tsunami and seismic related information and warnings. More than 50,000 weather reports and several thousand charts and digital products are disseminated through the WMO GTS daily. WMO is building on its GTS to achieve an overarching WMO Information System (WIS), enabling systematic access, retrieval, and dissemination and exchange of data and information of all WMO and related international Programmes. WIS will also be able to provide critical data to other national agencies and users dealing with many sectors including disaster risk management;

③ **WMO Global Data-Processing and Forecasting System (GDPFS)** involves three World Meteorological Centres and 40 Regional Specialized Meteorological Centres, including Regional Specialized Meteorological Centres (RSMCs), Regional Climate Centres (RCCs) and Regional Drought Management Centres. They process data and routinely provide countries with analysis and meteorological forecasts, supporting early warning capacities through the NMHSs.

④ In addition, WMO supports 30 Regional Training Centres, providing technical training for management and operations of the NMHSs. Building on this network, WMO is working with its Members to strengthen and establish new Regional Climate Centres (RCCs) and Regional Drought Management Centres (RDMCs). To date, RCCs have been established in Beijing (China), Tokyo (Japan), and a pilot phase is being introduced in Europe and Africa. Africa has established two drought monitoring centres and a RDMS for South-Eastern Europe has been set up in Slovenia in collaboration with the United Nations Convention to Combat Desertification (UNCC).

Multi-sensor hydrometeorological monitoring networks, composed of a gauge, radar, and satellite sensors, collect rainfall, temperature, and other data that are used by forecasting models to produce flash flood guidance and threat information. Hydrometeorological monitoring networks and associated communications are critical to the success of any flash flood early warning system. [20]

b) Hydrological monitoring networks

Today, more than ever before, the range of hydrological networks' objectives and the uses of collected data has extended. Along with conventional uses of hydrological information, such as water resources assessment, project design, water resources planning, hydrological forecasting and water quality control, new applications of hydrological data are gaining ground, such as environmental monitoring, flow accounting and monitoring of water quality in transboundary water bodies, development of local hydrological forecasting and flood warning systems, monitoring of water allocation processes and provision of data for management of water utilization systems. [22]

The measurement of surface flows is a complex scientific discipline that requires skilled practice of field observation. Direct flow measurement techniques are difficult to implement and poorly adapted to changing flow conditions. It is therefore necessary to use indirect approaches that require the measurement of one or more parameters and the construction of a calibration law to develop flow data (hydrographs). [23]

A hydrometric station is a location where the water level is continuously measured to calculate a flow. Other complementary measurements can possibly be carried out on the site: climatology, water temperature, even physico-chemistry of the water.

A hydrological network is composed of a group of stations (gauges) that are designed and operated to make observations under special observation programmes and address a single objective or a set of interrelated objectives. [22]

The goal of a monitoring network is to sample hydrological parameters at basin and national scales for multiple purposes such as:

- Water resources assessment and management;
- Hydrological system understanding and trend analysis;
- Flood and drought forecast and warning;
- Design of hydraulic infrastructure (flood protection, irrigation plans, hydropower, water supply, waste water management, navigation etc.).

Box 7: About best practice for monitoring network design [21]

The WMO guide 168 [24] presents best practice in monitoring network design and the WMO Commission for Hydrology is working on improving the optimization approach; the main points are summarized here:

- ① The current and future objectives of the monitoring network must be clear; all potential users nice to have the opportunity to expose their requirements. The most important point is to think in terms of information requirements, and not only data production;
- ② Network optimization is an iterative process and should be based on information theory and statistic approaches combined with a pragmatic approach (access, power supply, particular locations to be observed, length of existing data series etc.);
- ③ The validity of the network must be regularly assessed (every 5 years or so);
- ④ Ideally, the network should incorporate a few very stable, long-term stations, and other stations that could be replaced every 5 to 10 years. In addition, information should be incorporated from remote sensing, in particular satellites, and other data sources (citizens, academia, hydropower companies, farm communities with low-cost technologies, etc.);
- ⑤ As the length of the hydrological series is critical for many purposes, long-term future requirements and developments must be considered in planning network redesign.

Ideally, the whole hydrological cycle should be measured, combining standard surface runoff parameters with groundwater, soil moisture evapotranspiration, precipitation, snow and glacier, as well as water quality parameters. Although a national hydrometric network represents a small share of the budget per se and brings huge direct and indirect benefits, its investment and maintenance costs make it difficult to fully cover needs. Thus, optimization is required.

Stream flow gauges consist of some form of measuring device — in this case for water surface elevation measurement— a data collection platform (DCP), a power supply and management unit, and a communication device. Streamflow gauges estimate discharge by measuring the water surface elevation in the channel. This is then compared to a table or graph known as the stage-discharge relationship or rating curve, which is comprised of manual discharge measurements and the corresponding water surface height, to obtain an instantaneous estimate of stream flow. [20]

c) Water quality monitoring networks

The objective of water quality monitoring is to obtain qualitative information on the physical, chemical, and biological characteristics of water via statistical sampling [25]. The type of information sought depends on the objectives of the monitoring programme. Objectives and purposes range from detection of drinking water standard violations to determination of the environmental state and analysis of temporal water quality trends. Three main categories of monitoring can be identified:

- ① **Routine surface water monitoring,**
- ② **Periodic special surveys, and**
- ③ **Special surveys** performed to assess the extent of a pollution problem (e.g. a survey of pesticide occurrence in surface waters).

The state of water quality is the result of complex natural and man-made conditions and the consequent interactions in both time and space. Consequently, abstracting the essence of water quality conditions is often very difficult.

Monitoring purposes

Any attempt to evaluate water quality monitoring programmes should begin with the question "Why do we monitor?" It is very important to be able to describe the purposes and objectives of monitoring as they create the background for the direct monitoring activities, i.e. the set-up of sampling networks, variables to be measured, sampling frequency, data storage and information utilization, including data analysis and reporting.

The purpose of water quality monitoring is generally laid down by **laws or other regulatory actions** (directives, water quality standards, action plans) and aims at assessing the environmental state and detecting trends. The regulatory actions set up water quality goals or standards (e.g. a 50 per cent reduction of nitrogen loading in surface waters, no pesticides in drinking water, etc.), and the purpose of monitoring is to supply data and information on the water quality in relation to these regulatory actions.

In principle, there could be as many types of monitoring programme as there are objectives, water bodies, pollutants and water uses, as well as any combination thereof. In practice, assessments are limited to nine different types of operations: **trend monitoring; basic surveys; operational surveillance; background monitoring; preliminary surveys; emergency surveys; impact surveys; modelling surveys; and early warning surveillance.** [26] [27]

Box 8: Requirements, operation and maintenance of hydrological stations [21]

WMO Guide 168 [24] describes requirements, operation and maintenance of hydrological stations. In short, the following points can be highlighted:

- A station's equipment must match the measurement purpose, local conditions, and available financial and human resources to ensure its regular operation and maintenance. Modern devices and automatic transmission stations should be privileged, especially when regular high frequency data transmission to a central collecting point is required, but manual measurements should not be discounted for particular situations. Citizens' scientific observations, from both fixed and casual locations, can also be included;
- If a station is used for flood warning or any other real-time decision process, a fully redundant system should be considered: 2 different sensors, separated modems and loggers, different communication tools (GPRS, radio, satellite);
- Trained observers must regularly visit the station (depending on conditions, perhaps even weekly, but at least every 3rd month), take control measurements and document the observations. The performance of the measurement device should be regularly tested and the device calibrated;
- Especially for stations where discharge is derived from a rating curve, the latter should be regularly reevaluated, at intervals depending on hydromorphological conditions (stability of the river bed, sediment load, etc.).
- It is preferable to concentrate different parameter measurements at one well-equipped station, even if different organizations are in charge of the monitoring. For instance, it could be beneficial to measure, in addition to standard water level and discharge, the sediment load, temperature or other physical chemical and biological parameters as appropriate. This would facilitate analysis and understanding of processes;
- Observers and field hydrologists should benefit from continuous training to enhance their skills and make sure they are updated with the latest developments;
- Comparison measurements with different devices and different teams, e.g., in the form of a regatta, will help gain experience and ensure comparability of observations. Special attention should be paid to preventing station degradation due to vandalism and theft, especially for stations equipped with solar panels or other equipment that cannot be put in a locked room. Raising neighboring communities' awareness of the importance of the equipment and highlighting the benefits they can indirectly draw from their continuous functioning, will certainly help.

d) Groundwater monitoring**# Groundwater level**

Groundwater level measurement has proven to be indispensable to monitor anthropogenic-induced and/or natural changes in order to:

- Detect early signs of over-exploitation and/or other consequences of human impacts on groundwater levels (e.g. impact of hydraulic engineering, abandoned mines);
- Provide the necessary information allowing for 'tailor-made' use and need-oriented groundwater quantity management; and, provide information for the interpretation of groundwater quality data.

Water level is generally measured at the level of piezometers or using existing wells, boreholes or spring yield measurements.

Groundwater quality

As regards groundwater, monitoring normally includes testing for long-term changes of water quality in major aquifers so as to provide a basis for statistical identification of the possible causes of observed conditions and to provide the statistical basis for the identification of trends.

The following types of monitoring network can be distinguished:

- Basic networks;
- Specific networks;
- Temporary networks.

i) Case studies of regional and global data collection processes

Case study 3: WHYCOS - The World Hydrological Cycle Observing System [21]

Countries and basin organizations willing to develop their hydrological monitoring capacities can benefit from the support of WMO through the World Hydrological Cycle Observing System (WHYCOS) and its HYCOS projects. WHYCOS is a framework programme dedicated to strengthening hydrological observation activities, reinforcing international cooperation and promoting the free exchange of data in the field of hydrology. In 25 years, 12 projects were developed and around 500 measuring stations were installed. Yet, a new momentum is required to enhance the effectiveness of the HYCOS projects and ensure sustainability of the achievements. Accordingly, WMO launched in 2017 the Global Hydrometry Support Facility with the initial support of the Swiss government. Better known as the HydroHub, this facility aims to improve the full value chain from data collection to hydrological services through:

- Building on the WHYCOS experience to develop an efficient, innovative and sustainable framework to support operational systems in hydrometry in the world;
- Facilitating the operational uptake of innovative technologies by national services, including new technology, citizen science, better use of satellite products, low-cost devices, and information systems;
- Fostering the creation of a community of practice for operational hydrology to enhance information sharing and knowledge exchange;
- Promoting free and open data sharing with many stakeholders across communities;
- Bringing together actors from academia, public and private sectors to build benefit-sharing partnerships.

Hydrological data sharing will be facilitated through the development of WHOS Phase II, the new WMO Hydrological Observing System that aims to make hydrological data easily discoverable and accessible worldwide.

The WHYCOS framework aims to improve the efficiency and sustainability of the monitoring framework through:

- Better connection between data providers and all kinds of users, including political;
- Development of hydrological data services and products;
- A combination of different monitoring approaches and integration of data from different providers;
- Reinforced dedicated training and capacity building, including assessment of institutional and legal status of data provider organizations;
- A new financial model for HYCOS projects, including long-term maintenance and operation of stations;
- A reinforced open data policy.



Figure 5: Hydrologic data exchange by standardized service types and data formats in the Niger river basin

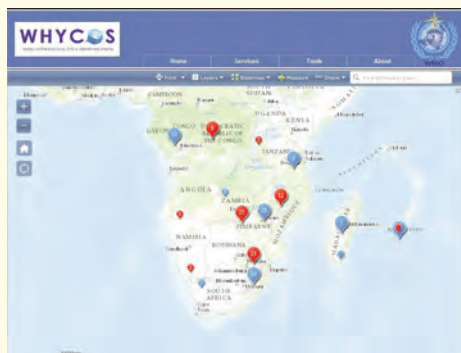


Figure 6: Hydrologic data exchange by standardized service types and data formats in the Southern Africa

Case study 4: Global Runoff Data Centre (GRDC) [28]

The Global Runoff Data Centre (GRDC) was created in 1988 at the German Federal Institute of Hydrology (BfG) under the auspices of the World Meteorological Organization (WMO). It is Germany's contribution to the WMO's Global Climate Observing System and Hydrology and Water Resources Programme.

The GRDC's global base comprises a unique collection of data on river flows collected daily or monthly by over 9,400 stations in 160 countries. This represents over 410,000 station-years with an average record length of 43 years.

The GRDC archives international data over a 200-year period and encourages long-term hydrological studies. Its objective is to help earth science specialists analyze global climate trends, evaluate impacts and environmental risks, and assist the assessment of transboundary water resources.

The Centre manages several specialized databases, including the bases of the WMO Hydrology Commission and the Global Terrestrial Network for River Discharge (GTN-R) to support the Global Climate Observing System (GCOS) in evaluating freshwater flows into the sea. In addition, the GRDC offers products like GIS maps showing major basins and catchment area boundaries for over 7,000 GRDC stations.

To expand and update its database, the organization relies entirely on voluntary contributions from national hydrological services and related authorities responsible for monitoring flows. National hydrological services and basin authorities are encouraged to supply relevant data so that the GRDC can satisfy requests for flow-related data for non-commercial uses in science and research.

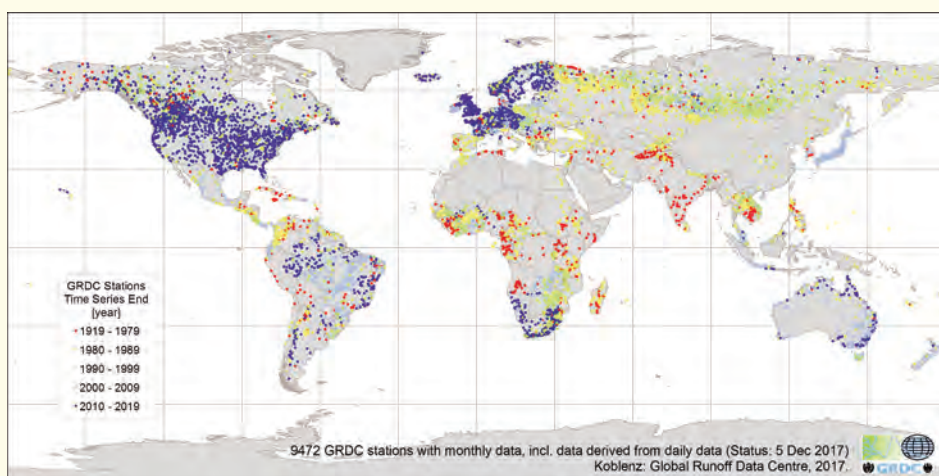


Figure 7 : 9472 GRDC stations with monthly data

3.2.2 Data production through remote sensing

“Remote sensing plays an increasingly important role in providing complementary data needed to confront key water challenges: [29]

- In poorly gauged basins, at time intervals of several days, real-time satellite estimates of **precipitation and derived streamflow forecasts** can help managers to allocate water among users and to operate reservoirs more efficiently;
- In large rivers, **data on river and lake surface elevation** (cf. case study on SWOT) can be used to estimate flow in the upper parts of the basin and to predict flow downstream;
- **Soil moisture** observations vegetation indexes and energy balances may give insight into how much irrigation is needed, as well as help to forecast and monitor drought conditions;
- Water managers in snow-dominated areas can use estimates of **snow cover and snow water equivalent** to assess how much water is in storage and determine what watersheds it is stored in;
- Remote sensing also enables the monitoring of many **parameters of surface water quality** to assess the repercussions of river basin management policies, land use practices, and non-point-source pollution as well as the likelihood of algal blooms and other threats to the quality of water supply systems;
- In situations involving the food-water-energy nexus, governance and adaptive management, or transboundary settings, remote sensing may help decision makers to adjust past policies or facilitate early warnings by providing information from parts of a basin lying outside a nation's borders;
- Monitoring fragile ecosystems, in particular wetlands and peatlands providing a solution of a global coherent approach for monitoring SGD 6.6 and indicator 6.6.1 “Change in the extent of water-related ecosystems over time”;
- Remote sensing is a key component for innovative climate services that support operation adaptation measures for agriculture production, flood and drought management,
- ...

There is also great potential for remote sensing data use in operations related to climate variability and change, agricultural systems, and water systems planning and management.

Actual or planned uses of remote sensing products vary from the evaluation of a project's impact on agricultural water management, agricultural water-saving measures, and support services to the provision of input for modern, basin-wide water resources information systems; feasibility studies; basin planning, monitoring, and forecasting; transboundary options for mitigating flood risks; investment planning and basin decision support systems; and institutional or community planning frameworks for addressing environmental and social issues.” [29]

Box 9: Identification of relevant remote sensing datasets for water resources management [30]

Through a series of summer training courses [31, 32], UNESCO-IHP has engaged with its member states, in collaboration with NASA, to identify relevant remote sensing datasets for water resources management. A detailed assessment of remote sensing datasets is also provided in the recent review paper on Satellite Remote Sensing for Water Resources Management [30]. In these references, additional information can be found on each aspect of the water balance, including precipitation, evapotranspiration, streamflow, water levels, soil moisture, snow and ice, groundwater, water quality, as well as indirect components, such as vegetation density, forest biomass and crop water and land surface temperatures. An overview of remote sensing data availability from remote sensing data sources is provided in Table 1.

Variable	Spatial Coverage	Temporal Coverage	Utility for WRM
Precipitation	Extra-polar regions to global	10-15 years for sub-daily data; near real-time.	Essential in regions with sparse in-situ networks, but short time series
ET	Regional to global	Decades; near real-time	Global and decadal coverage but high uncertainties
Streamflow	Limited to large rivers	Years to decades; limited availability in real-time	High uncertainties and limited coverage, but essential where available
Water levels	Water levels Limited to large rivers and water bodies	Years to decades; in real-time	Limited coverage but useful for specific water bodies
Soil moisture	Global	Years to decades; available in near real-time	Limited depth; but useful if combined with models
Snow and Ice	Global	Years to decades; available in near real-time	Essential, but high uncertainties for SWE, more accurate for snow covered area.
Groundwater	Global, but coarse resolution	Years; coarse resolution	Coarse resolution prevents direct use, but has research applications and useful when combined with models
Water Quality	Global	Years; available in near real-time	Limited variables, and high uncertainties depending on the variable

Table 1. Relevant variables for water resources management from remote sensing sources (adapted from [30])

Case study 5: SWOT Satellite - Remote sensing program [33]

The last 30 years have seen a sharp decline in hydrological databases around the world, particularly in Africa. Spatial altimetry makes it possible to complete the in situ measurement network in order to densify data and ensure better hydrological monitoring.

The **Surface Water and Ocean Topography** (SWOT) programme is a French-American Earth observation satellite with contributions from UKSA and CSA that by 2021 will monitor water level variations of major streams, such as lakes and rivers, estimate runoffs from rivers and monitor ocean levels. The SWOT mission uses a new, as-yet untested technology: wide swath altimetry.

This development constitutes a real technological breakthrough which aims to provide measurements with an unprecedented precision and to improve our understanding of the water cycle. Although SWOT is mainly a scientific satellite, it offers a great potential for the development of new applications and services with significant economic and societal impacts.

As part of the Future Investment Program, CNES* has set up a preparatory programme, the SWOT-Downstream programme. Its goal is to develop products tailored to end-users' needs integrated into existing or future services, and to prepare water stakeholders for the use of these new data from space. In Hydrology, the SWOT-Downstream programme focuses on preparing the hydrology user community by sharing simulated SWOT datasets. It also shares multisensory hydrology derived products, such as soil moisture, water levels, land cover, etc., supports and promotes scientific work in space hydrology, and associates customers and service providers in the development of new applications. Most SWOT-Downstream activities will be gathered in a global "Water Database" portal (see figure below).

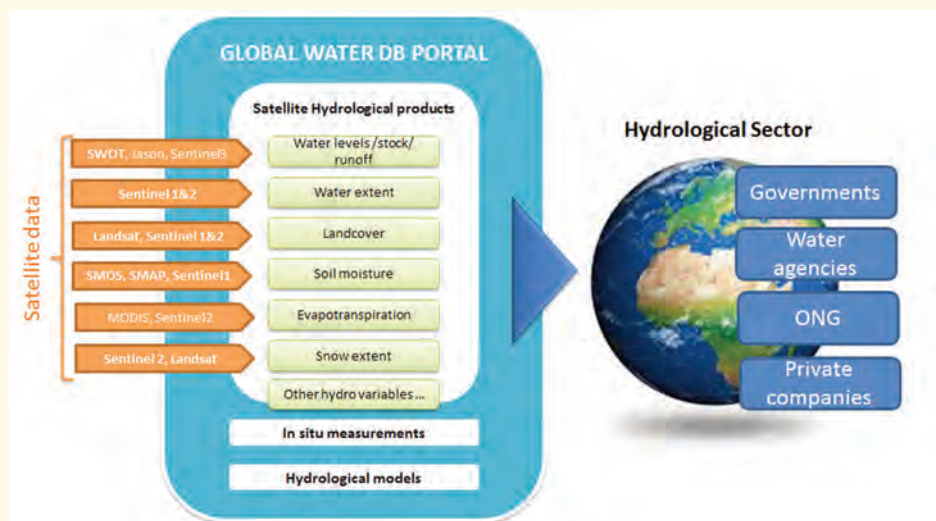


Figure 8: Space Water Database HYDROWEB NG

A working group has been set up to demonstrate all the space data capabilities in hydrology. The Congo basin is the first pilot site. Applications in development include monitoring the Congo water level and discharge and forecasting navigation and hydropower capacity as well as a water information system. All of this work covering the Congo basin is financed by AFD and CNES.

[* CNES is the public institution responsible for proposing and conducting France's space policy within Europe; CNES develops space missions and supports user communities in the exploitation of spatial data.]

Case study 6: Remote Sensing Based Agricultural Drought Monitoring and Yield Loss Prediction Method [34]

Multispectral remote sensing technology is widely used in agriculture and is appropriate for vegetation analysis [35]. Vegetation has characteristic spectra, often showing characteristic absorption maxima or minima at particular wavelengths. Most vegetation indices are based on the sharp increase in reflectance from vegetation that occurs around 700 nm (the red-edge), a change that is characteristic of green vegetation and not found for most other natural surfaces that show relatively slow changes of reflectance with wavelength over this region [36]. In particular since 2002, new opportunities exist for producing better data for calculations thanks to the MODIS Aqua and Terra satellites, which provide free 36-band numbers, with 1-day repeating cycles and 250 to 500 m pixel size time series data sets. For agricultural water management today, remote sensing time series analysis (RS-TSA) is one of most important solutions for measuring agricultural droughts and their effects [37].

This case study, developed in the framework of ICPDR activities, aims to fill the knowledge gap in this field by developing agricultural drought-related decision parameters and applying them in practice from raw spectral datasets. Signaling levels of this activity, and free-of-charge available homogeneous remote sensing data (MODIS NDVI spectral indices) and land use (CORINE database) datasets, can be applied on national and Central and Eastern European scales.

The methods and databases explored include employment of remote sensing data on land use, as well as biomass production, soil characteristics for better integration and understanding of cropping patterns influenced by hydrology and soil types. Internationally available land use (CORINE database, topographic maps) remote sensing data, MODIS NDVI spectral indices, soil data (agro topographic map, soil water management properties, map of water management properties of soils), hydrology (soil water table), and digital elevation models have been processed and integrated to determine yield loss thresholds and soil water-holding capacities.

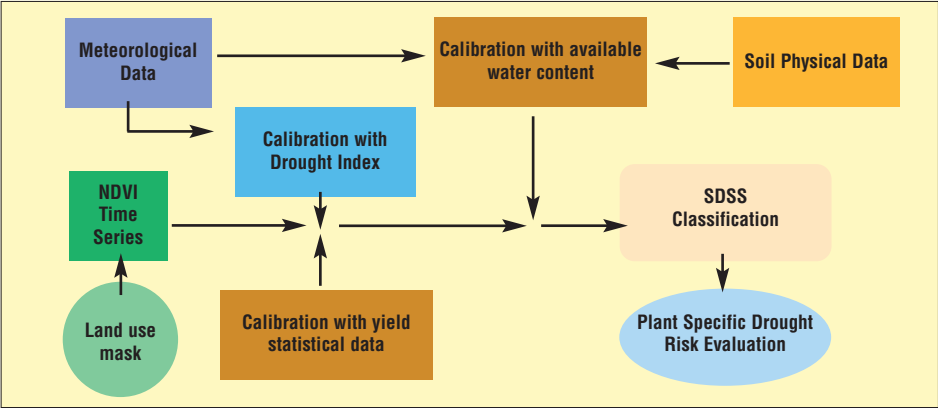


Figure 9: Main steps of the applied model/ICPDR

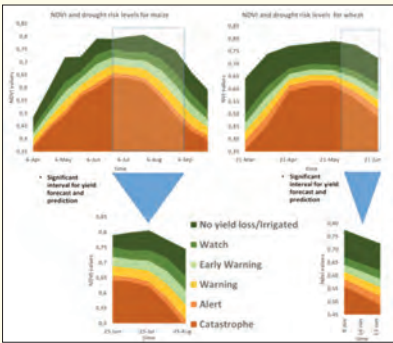


Figure 10: Drought risk and signaling NDVI levels for maize and wheat

3.2.3 Data production through crowd sourcing

The paucity of solid water-related data in many developing regions of the world today is an expression of decades of governmental neglect to invest adequately, in particular in hydro-meteorological and agro-meteorological data production.

Thanks to the emergence of new mobile technologies and software as well as hardware integration, the acquisition of relevant data through local involvement is a new global emerging trend that is seen as an opportunity to fill some gaps of traditional data.

The crowd sourcing of such non-traditional data is, however, not without challenges. For example, recent global crowd-sensing initiatives such as the Weather Observation Network (see <https://www.metoffice.gov.uk>) show that if the approach depends exclusively on voluntary participation of citizens, the spatial and temporal resolution of the collected data highly correlates with a) the population density and b) the development status (GDP) of a certain region/country. Many observations are therefore made in urban areas of industrialized countries, where an existing meteorological network of automated sensors/stations already contributes to high data availability. At the same time, the approach fails to increase data availability in data-poor rural areas in developing countries. Hence, key questions remain in relation to data acquisition through local involvement in the development context. They range from issues related to the precision and timeliness of these crowd-sensed data to ensuring the long-term steady motivation of crowd-senders, i.e. the people involved. [38]

Box 10: Contribution from WMO to innovation related to hydrological monitoring [21]

Emerging technologies allow innovative ways to measure hydrological parameters that should support efforts to establish water information. WMO is set to benefit from these new developments through its Innovation Hub, a component of the WMO HydroHub. In addition to scouting and supporting uptake of innovative approaches in operational environments involving emerging monitoring approaches including crowd sourcing, WMO will make sure that data from very different sources of varying quality are incorporated into a comprehensive hydrological information system thanks to a new standard approach.

Case study 7: Case study of the iMoMo project - Acquisition of Non-Traditional Data through Local Involvement [38]

An example of a large-scale, multi-year trial to collect data on water levels and discharges in small- to medium-scale canals as well as rivers in the context of dry land irrigation was carried out as part of the global iMoMo Initiative (www.imomohub.org). The latter was supported by the Swiss Agency for Development and Cooperation and was part of a drive for innovation in data acquisition, management and exchange, and an overview to help to address global water resource challenges in the context of population growth and increasing climate uncertainty. The device is currently in use in communities in Tanzania, Kyrgyzstan and Uzbekistan and is valued by local stakeholders because it allows incontrovertible water level readings and thus helps to ensure compliance with on-farm community-based water allocation rules.

In addition, an Android app for smartphones has been developed for measuring water levels and discharges based on an optical method that uses a mobile phone camera. The app provides a non-intrusive, accurate and cost-effective measurement method. The process of setting up a new site should ideally be conducted by experts and include measuring the cross-sectional area at maximum flow and the relative distances between four markers on both sides of the shoreline. Once a site is set up, even a non-expert can carry out a measurement in under a minute. What is more, the App allows seamless data transmission to a dedicated cloud database via GSM/Wifi/SMS. The database can be accessed using a web application in a browser (see <https://discharge.ch>). The web application allows easy data visualization and data analysis. The app has been deployed in Tanzania, Uganda, Kenya and Ethiopia as well as in parts of Central Asia and is currently undergoing continued pilot testing in selected basins there.

cont'd

Figure 11: Mirabs in Kyrgyzstan testing the SmartStick device for measuring water levels



Figure 12: Measuring discharge of a small irrigation canal with 2 different smartphones in Tanzania for comparison.

Despite the attractiveness of technologies such as those mentioned above, key lessons from the global iMoMo Initiative have shown that several important preconditions need to be in place for crowd-sensing campaigns to be successful in the sense that they can fill existing data gaps and thus help to improve stakeholders' decision-making at different water resource management levels. As an example: 1/ clear visions need to be formulated by local stakeholders concerning the usage potential of non-traditional data; 2/ stakeholders from government agencies often show reluctance to promote and adopt these technologies due to non-compliance with national standards and agency underfunding; 3/ proper workflows need to be established, including data collection protocols; 4/ a stringent quality assurance and control process (QA/QC) needs to be put in place; 5/ a dedicated service should be made available to monitor data-collection efforts in a consistent fashion and chase up citizens who fail to deliver data as agreed.

Box 11: Crowd sourcing for water quality control [39]

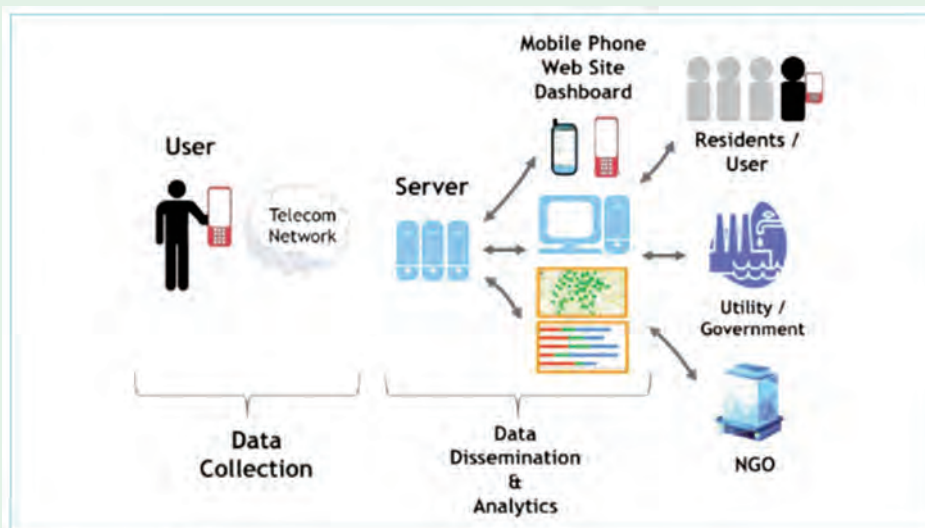
A traditional water quality monitoring infrastructure is expensive and requires laboratories, sophisticated testing technologies, specialists to conduct tests and comply with sampling and testing protocols, and information systems to control and manage data flows and reporting.

Recent technological developments in sensors and telemetry are revolutionizing the monitoring landscape, enabling the collection of high-frequency data from remote locations with high accuracy.

Mobile phone technologies coupled with water quality testing create great opportunities to increase the awareness of water quality in rural and urban communities in developing countries. Whether the focus is on empowering citizens with information about the quality of water they use every day, or providing scientific data to water managers to help them deliver safe water to citizens, the integration of citizen science, crowd sourcing, and innovative technologies has the potential to create positive and lasting change.

The crowd-sourcing framework develops a strategy to engage citizens in measuring and learning about the quality of their own drinking water. Through their participation, citizens provide utilities and water supply agencies with cost-effective water quality data in near-real time. In a typical crowd sourcing model, consumers use their mobile phones to report water quality information to a central service. That service receives the information, then repackages and shares it via mobile phone messages, websites, dashboards, and social media. Individual citizens can thus be informed about their water quality, and water management agencies and other stakeholders can use the data to improve water management; the result is a win-win situation.

Box 11: cont'd



Source: Hutchings et al. 2012.

Figure 13: Data collection and dissemination for mobile phone applications

Massive participation in data collection could lead to better water management of water systems that lack adequate monitoring technology.

3.3 Integrated data management and data-sharing organization

KEY POINTS:

- Integrated data management supposes building any new data management process relying on existing systems;
- Rules and strategies should be adopted with the stakeholders who produce and manage data;
- An analysis of the existing situation can avoid duplication and create synergies;
- Elements of a common language are required to insure data comparability;
- New Internet technologies facilitate the development of interoperability (automatic data exchanges) between existing information systems.

When working at regional, transboundary, national or basin level, the creation of a water information system to produce information never starts from scratch.

The following always already exist:

- Data producers with their own staff and data-collection procedures;
- Operational information systems with specific procedures and data structures for digitizing/controlling/archiving/processing the data;
- Data/information exchanges between organizations following specific procedures.

Therefore, in order to build on existing systems and not reinvent the wheel when organizing a new water data management process, the following are recommended:

- Adopt some basic principles to ensure successful cooperation between actors;
- Start with a diagnostic phase that could help to identify:
 - The real needs to be covered in terms of information production;
 - The actors/institutions involved in data production/ management and information use and their specific roles;
 - The datasets that exist and the information systems already set up, and the conditions to access and use the data (level of confidentiality, technical conditions of access, etc.);
 - The existing data and information flows already established between the partners;
 - Partners' needs in terms of data access, reinforcement of their tools, developing the capacity of their human resources, and what could encourage them to participate in a process of regular data exchange.

In many cases, the following might also be important:

- Develop elements of common language in order to insure the comparability of data exchanged;
- Establish procedures facilitating interoperability between the existing water information systems.

3.3.1 Elements of strategy

For organizing the rules with stakeholders, basic principles such as those defined by the SEIS can generally be recommended.

Box 12: About the Shared Environmental Information system (SEIS) principles

On 1 February 2008, the European Commission adopted a communication on SEIS. The main principles are described as follows:

- Information should be **managed as close as possible to its source**;
- Information should be **collected once, and shared with others for many purposes**;
- Information should be **readily available to public authorities and enable them to easily fulfil their legal reporting obligations**;
- Information should be **readily accessible to end-users, primarily public authorities at all levels from local to European, to enable them to assess in a timely fashion the state of the environment and the effectiveness of their policies, and to design new policy**;
- Information should also be **accessible to enable end-users, both public authorities and citizens, to make comparisons at the appropriate geographical scale (e.g. countries, cities, catchments areas) and to participate meaningfully in the development and implementation of environmental policy**;
- Information should be **fully available to the general public, after due consideration of the appropriate level of aggregation and subject to appropriate confidentiality constraints, and at national level in the relevant national language(s); and**;
- Information sharing and processing should be supported through common, free open standards.

In application of these basic principles, considering that the data has to be managed as close to the producer as possible, it might be important to support the data producers to establish their own database/information system (or have access to an external one) and so manage/process their own data and insure its quality control.

At the second stage, in order to facilitate the aggregation/processing of data to generate information, links can be developed between the producers and the data managers who generally act:

- At national level, through national thematic databases/information systems for production of national information;
- At basin level, for basin water management;
- At local level, for local water management. [6]

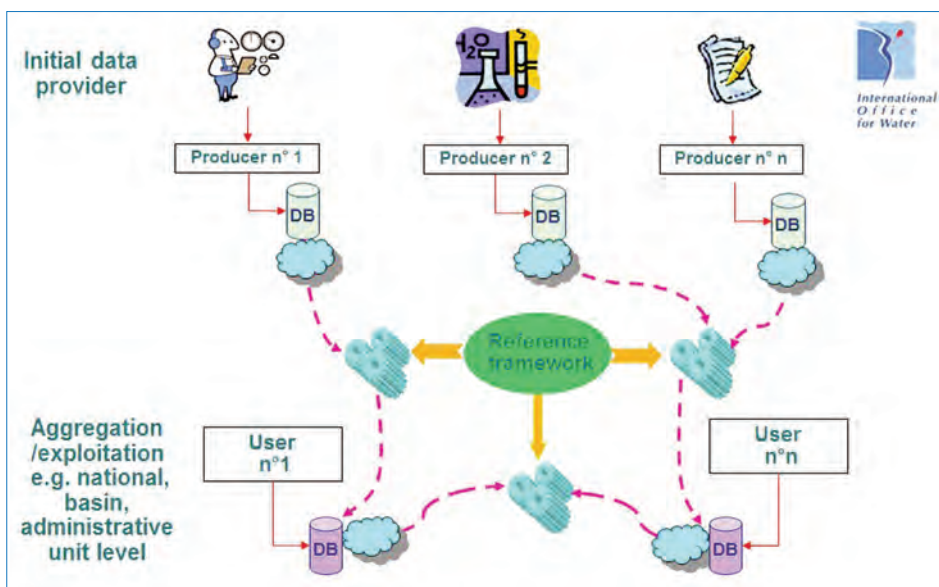


Figure 14: Example of global scenario for an efficient water data exchange

In addition, the strategy should also include a quality check procedure and insure that the whole chain from data to final user can be traced, with in particular the production of metadata by each data producer.

The recommendations presented in the box below by WMO for Hydromet data management could be adapted and applied to all data topics.

Box 13: Elements of strategy for Hydromet data management/WMO vision [21] [24]

Data are harnessed by very different users for very different purposes, at very different frequencies and with different tools and approaches. Such data might be used in real time - for managing an emergency situation for instance - or for long-term planning and project design using historical time series. Accordingly, data collection and management must take into account this diversity of goals. Data must be accessible, reliable, trustworthy, understandable and sharable, even decades after having been collected. Time series of key locations must be as long as possible, with few interruptions. These criteria set the scene for water data governance:

- Data quality checks must be regularly performed and complete meta information must consistently support the actual data: WMO provides support to data providers thanks to regulatory material such as *The WMO Guide to Hydrological Practices* [24] and with projects such as the “Assessment of the Performance of Flow Measurement Instruments and Techniques”;
- The whole data chain, from collection to users, must be traceable, consistent and uncorrupted. National Hydrological Services play the crucial role here, with technical support and advice from WMO;
- Data from different sources (including, in addition to standard stations, low-cost technology, innovative approaches, satellite products, etc.) must be portable - thanks to standard data formats such as the OGC-WMO WaterML 2.0 - and quality assessment;
- Long-term series must be secured and stored in different, distant locations. Paper hydrographs must be digitalized and secured. As recent decades have seen a continuous evolution of data support media with rapid obsolescence of technologies (punch cards, tapes, disks, flash cards, cloud) it is of paramount importance to ensure the migration of all data to the next generation support, in order to guarantee the integrity of the historical series, as old supports become rapidly incompatible with new hardware and software;
- A data management system must simplify quality assurance /quality control operations and preparation of data products (bulletins, regular overviews, statistics, model inputs, forecasts, outlooks, etc.). Except when immediately needed for short-term forecasting, all data shall be quality checked and validated. Data management systems must store raw and corrected data separately, and allow for documenting the changes made to the raw data;
- A data portal must facilitate data discovery, visibility and sharing among different users. The status of each datum (raw, provisional, validated, and corrected) as well as all relevant metadata must be easily accessible and exploitable by the users.

3.3.2 Diagnosis of the existing situation on data management

Considering the multiplicity of data producers and data collection processes, and considering that the information system must be built on the existing situation avoiding duplication of activities and respecting the roles of each partner, a diagnostic phase can help to establish a clear vision of:

- The roles and activities of the actors, including:
 - Who is supposed to do what in the field of water data administration?
 - Who produces what, specifically?
 - Who needs what data and what information?
- What are the characteristics of the existing datasets and existing information systems managed by the main actors?
- What are the existing regular data exchange flows between actors?
- What are the needs of the various actors?

The potential outputs of the diagnostic phase (metadata catalogue, dataflow diagrams, data dictionaries of existing information systems, etc.) generally help to:

- Identify the data producers likely to be involved in the process;
- Select the datasets to be collected in order to produce the expected information;
- Identify the issues of data comparability that will have to be solved when combining;
- Specify the global architecture of the system and procedures for data exchange and dissemination organizing the interoperability between the various systems;
- Define the main tools for data processing and information production/dissemination;
- Agree on the rules of the system's governance between the partners involved.

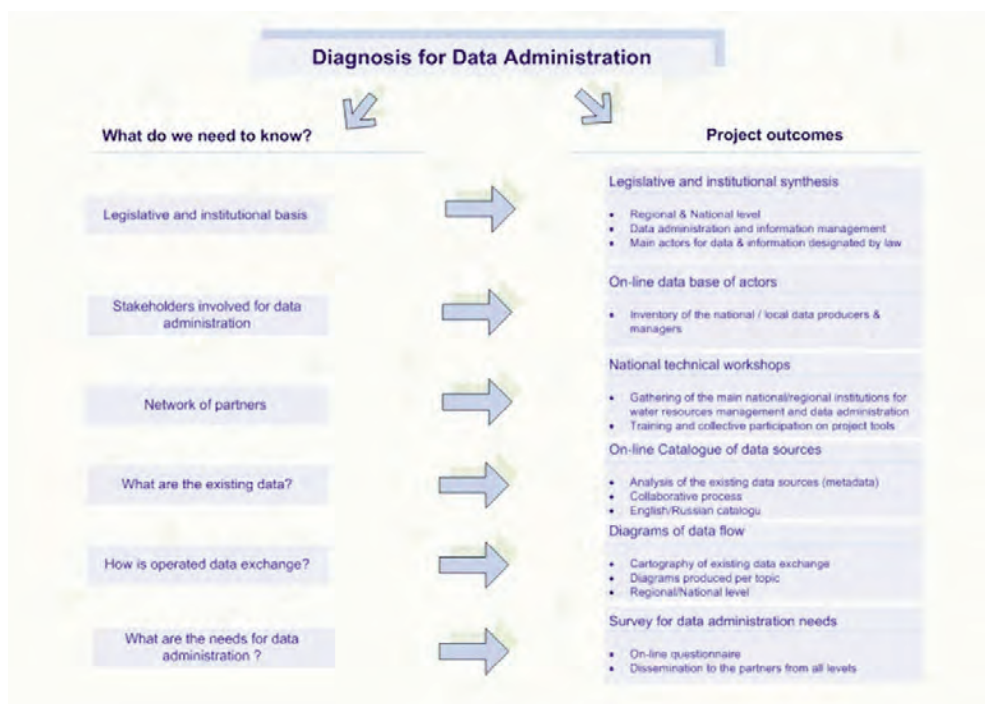


Figure 15: Potential outputs of the diagnostic phase

Specific attention should be given to the production of metadata, which are “data about data”.

Indeed, to facilitate traceability and ensure that data are not misused, the assumptions and limitations affecting the creation of data must be fully documented. Metadata allow a producer to describe a dataset fully so that users can understand the assumptions and limitations and evaluate the dataset's applicability for their intended use.[40]

Case study 8: Metadata catalogue for a collaborative inventory of data sources [17]

In the frame of various water resource management projects carried out in Eastern Europe, Central Asia, Latin America, and South East Asia, IOWater supports national authorities in developing their online metadata catalogue. Such a tool facilitates the inventory and description of available data sources and makes them easier to discover. After a configuration phase, the online tool is generally presented at the national data management workshops, and a specific password is given to each institution to allow them to capture online the descriptions of their data sources.



Figure 16: Metadata catalogue Interface for data discovery



Figure 17: Example of selection of a metadata sheet

Case study 9: WMO approach in relation to data inventory [21]

Many hydrological studies and analyses require the availability of long time series. Experience shows that a significant amount of time within a project is dedicated to identifying, accessing and formatting appropriate datasets. Thus, it is strongly desirable to ease the data discovery process through data portals. Examples from academia are for instance the CUAHSI portal (Consortium of Universities for the Advancement of Hydrologic Science, Inc, <https://www.cuahsi.org/data-models/portals/>) which allows to publish datasets on a voluntary base. The GEOSS platform of the Group on Earth Observations can also be cited.

The WMO Commission of Hydrology is developing the new phase of the WMO Hydrological Observing System WHOS as the hydrological contribution to the WMO Integrated Global Observing System (WIGOS), the over-arching general framework for the coordination and optimized evolution of all WMO observing systems. In its current version, WHOS is a simple pointer system, a map interface that allows access to available datasets of national hydrological services which open their data (<http://www.wmo.int/pages/prog/hwpr/chy/whos/index.php>). However, discovering and downloading data, and making use of them for an intended purpose can still be tedious as metadata are not easily available and data formats may be different; furthermore the national web portal may be in languages not familiar to the user. In its next version, WHOS should provide users with a user-friendly brokering system that allows easy discovery and download capacities of existing historical and real-time data, from national services and from other acknowledged sources. It will be a fully WIS/WIGOS-compliant, services-oriented framework linking hydrologic data providers and users through a hydrologic information system enabling data registration, data discovery, and data access. A primary concern of WMO being data quality assessment, quality checks and meta information will build trust in the datasets.

(Cont'd)

Long time series of historical data are gathered and distributed by WMO Global Data Centres such as the Global Runoff Data Centre for Surface Runoff, hosted by Germany, the International Groundwater Assessment Centre hosted by the Netherlands and especially its Global Groundwater Network (GGMN) for Groundwater and the Hydrology of Lakes and Reservoirs (HYDROLARE) Centre, hosted by the Russian Federation.

These WMO Global Data Centres fulfil the following main duties:

- Collect and provide hydrological time series with database management systems
- Contribute to data rescue
- Support data collection efforts and data management projects
- Coordinate and disseminate information about national data holdings and about the conditions of data access, data quality and meta-information

3.3.3 A common language for data comparability

a) Why a common language?

The water domain is vast and characterized by the large number of actors involved in the regulation, management and use of water: ministries with their decentralized services, public institutions such as water agencies, local authorities, public and private companies, associations, etc.

Individual producers usually produce their own datasets for their own needs and following their own procedures. The pooling of these sources of data is a strong necessity, but it comes up against the lack of clear rules that would ensure comparability and exchange of data.

Some difficulties encountered with data exchanges



Figure 18 : Data exchange without common language

Using a common language to facilitate data exchanges



Figure 19: Data exchanges with common language

Without a common language, water data are therefore heterogeneous; each producer establishes its own nomenclatures, its own definitions of scientific words, its own computer exchange formats, etc.

However, when the various partners involved in water data exchange at national or regional level agree on a common language to be used when exchanging datasets, the result is fewer interfaces, easier comprehension of the data made available, and an open door to automatic data exchange and data processing.

These elements of a common language should include common concepts, definitions and coding systems, in order to be efficient and to ensure:

- A common understanding of the objects, their relations and behaviour (for example, to describe a monitoring station, how an abstraction is related to a measurement station, or the set of operations that is carried out from the creation of the data until its publication);

- The definition and use of a common system of identification, so that the same name is used everywhere to identify the same resource (for example, to identify a measurement station or a physico-chemical parameter).

Box 14: WaterML, a standard for hydrological data exchange [21]

Even at the beginning of the 21st Century, standards for hydrological data exchange formats are rudimentary and not widely implemented, in spite of an obvious need for transboundary cooperation, global hydro-climatological assessment and virtual water exchange computation for instance, thus making the ingestion of data from different sources an extremely time consuming activity

To bridge this gap, WMO, together with the Open Geospatial Consortium (OGC) developed and adopted the WaterML 2.0 standard for data sharing as a support to WHYCOS, WHOS and Flood Forecasting Initiative efforts, among many other activities of the international hydrological community. Once fully implemented, WaterML 2.0 will allow an easy sharing of time series, rating curves, water quality parameters and groundwater data among others.

Encoded in eXtensible Markup Language (XML) and based on existing OGC standards, WaterML 2.0 provides an interoperable hydrological exchange format that may be used to address a wide range of user needs. Using WaterML 2.0, it is possible to link together local, national, regional and global water information sources as part of global water information networks. These include the exchange of data relating to:

- In situ observations at hydrological (gauges, reservoirs) or climatological stations;
- Forecast products (probabilistic or deterministic time series) at forecast locations;
- Emergency or operator-oriented alerts (of threshold exceedance) and reports;
- Time series of planned intake and release/discharge;
- Groundwater observations of the water level within wells.

The availability of such a format will also facilitate the usability of data shared through the WMO Information System (WIS). WaterML 2.0 part 1 (Time Series) and part 2 (Ratings, Gaugings and Sections) have been adopted by WMO and included in its regulatory material

Case study 10: Use of WaterML 2.0 by the United States Geological Survey (USGS) [21]

This case study illustrates advanced data provision using WaterML 2.0 and other methods by the USGS, providing a freely available instantaneous values service providing access to streamflow and other real-time data from thousands of US monitoring stations, as well as a daily values service and groundwater levels service over the Internet. In March 2014, support for provision of time series data in the WaterML 2.0 format was added to these services.

This data is used for water resource management, monitoring floods and droughts, bridge design and for many recreational activities. Through its National Water Information Service (NWIS - USGS Water Data for the Nation. <http://waterdata.usgs.gov/nwis>), USGS provides summary reports, maps, statistics and other information via the Internet as well as the data services designed for machine-to-machine access via automated tools. These 24/7/365 operational services provide access to streamflow, water level and other data from over 50,000 surface water and 800,000 groundwater monitoring stations across the USA. More than 15,000 of the monitoring stations report in near real-time.

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As automated approaches to data access become more common, use of USGS water data services is increasing at a faster rate than more conventional web page access through as shown in the figure.

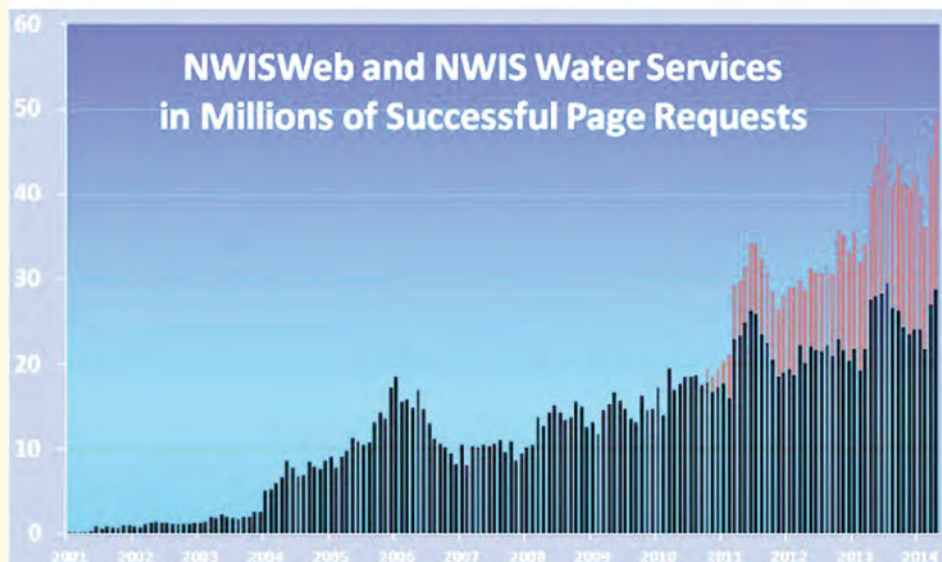
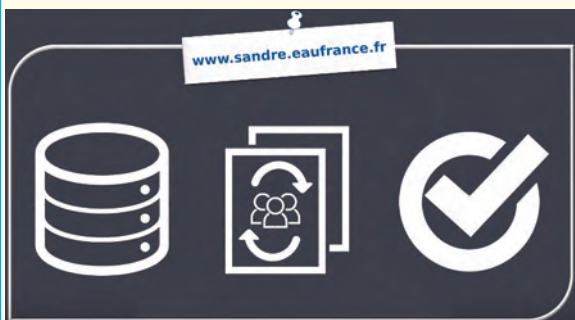


Figure 20: Growth in use of USGS water data distribution methods (page requests per month)

Data provision by USGS represents the current state of the art in real-time access to discharge and water level data encoded in WaterML 2.0. Using the USGS service, it is easy to create a persistent URL (web address) that provides a link to the latest discharge data for any site. For example the WaterML2.0 service for the Colorado River at Austin, Texas is available at: <http://waterservices.usgs.gov/nwis/iv/?format=waterml,2.0&sites=08158000&period=P1D¶meterCd=00060>.

Case study 11: France/ SANDRE [17]**# Missions**

Sandre's mission is to build and make available the French WIS's water reference data sets. These reference datasets are made up of free-of-charge technical specifications and code lists and describe how to exchange water data at the scale of France. From an IT perspective, Sandre guarantees interoperability between the French water information systems.

**# Regulations**

The National Scheme of Water Data (SNDE), supplemented by technical documents including those of SANDRE, must be respected by all contributors to the Water Information System (WIS), in accordance with Decree No. 2009-1543 of 11 December 2009. The state establishes which elements of the data repository must be used for applying the regulations, and the conditions of their use.

Organization

SANDRE comprises a network of organizations that contribute their business knowledge to the WIS, participate in the administration of the reference system and ensure the coherence of the whole. SANDRE has data administrators within the WIS contributing agencies. Led by the French Agency for Biodiversity (AFB), the network relies on the SANDRE Technical Secretariat provided by the International Office for Water (OIEau) which has driven, developed and made available the standard since its inception.

Composition of the repository

The Sandre Repository is a set of specification documents, reference datasets and freely distributed services namely: data dictionaries, exchange scenarios, administration documents, reference datasets, and assistance services.

3.3.4 Developing interoperability between information systems

Interoperability is the ability of a computer system, whose interfaces are fully known, to operate with other existing or future computer systems without restriction of access or implementation. The implementation of interoperability is pertinent when one information system has to exchange data automatically with another.

The principles of interoperability must be agreed by the stakeholders and written in a document describing the chosen protocols.

The architecture must be based on free computer standards, with oriented Internet preference (W3C, OGC, ISO, etc.).

The "no intrusion" principle allows all parties to manage their information systems independently of common interoperability rules. To strengthen everyone's acceptance, the

architectural document should preferably be written in the language of the country, comply with the regulations in force, and be introduced into the law.

The architecture document and the common language (see previous chapter) guarantee the semantic and technical interoperability of information systems.

Box 15 : About the interoperability standards used with GIS technology [9]

The unique integration capabilities of a GIS allow disparate data sets to be brought together to create a complete, concise picture of a situation. GIS technology illustrates relationships, connections, and patterns that are not necessarily obvious in any one data set, enabling policy makers, organizations and governments to make better decisions based on all relevant factors. To fully exploit the capability and benefits of geographic informations and GIS technology, spatial data need to be shared and systems need to be interoperable [41]. Indeed, GIS technology is used to share crucial information across organizational boundaries via the Internet and Web Services. Interoperability enables the integration of data between organizations and across applications and industries, resulting in the generation and sharing of more useful information. In that sense, GIS technology provides the framework for a shared spatial data infrastructure. In the geospatial community, the meaning of “interoperability” remains somewhat ambiguous, as do many of the benefits of “being interoperable”. Therefore, the following interoperability mandate is suggested: *“To be interoperable, one should actively be engaged in the ongoing process of ensuring that the systems, procedures and culture of an organization are managed in such a way as to maximize opportunities for exchange and re-use of information and services, whether internally or externally.”*

It should be clear that there is far more to ensuring interoperability than using compatible software and hardware, although that is of course important. Rather, assurance of effective interoperability will require often radical changes to the ways in which organizations work and, especially, in their attitudes to information. Within this context, Member States and other stakeholders should share, coordinate, and communicate key concepts between their own departments or between separate countries and organizations using GIS as the central spatial data infrastructure [42].

This is where the work of the Open Geospatial Consortium (OGC) and other standards organizations (e.g. Environmental Systems Research Institute) can be leveraged. Technical interoperability typically consists of selecting and implementing the appropriate software and/or Internet interface specifications, common content encodings for transmission, and so forth. Quite often, within the enterprise, technical interoperability is the easiest to achieve. Today, most GIS products directly read and sometimes dynamically transform data rapidly. The GIS community has been pursuing open interoperability for many years, and the solutions to achieving this goal have changed with the development of new technologies.

An open, distributed, networked GIS architecture provides the framework for sharing data and services. An open GIS system allows for the sharing of geographic data, integration among different GIS technologies, and integration with other non-GIS applications. It is capable of operating on different platforms and databases and can be scaled to support a wide range of implementation scenarios, from an individual consultant or mobile worker using GIS on a workstation or laptop, to organizations that support hundreds of users working across multiple regions and departments. With the introduction of web services, distributed multivendor GIS services can be dynamically integrated into applications using the interoperable standards of XML and SOAP. This level of integration already works on desktops. As a result, geographic data can be shared through OGC standard protocols such as WMS (Web Map Service, for serving georeferenced images) and WFS (Web Feature Service, allowing requests for geographical features), on other databases, or in GIS applications such as QGIS and ArcGIS.

Case study 12: Example of interoperability: Automatic exchange of data produced by water quality control laboratories in France [17]

In the French WIS, automatic data exchanges have been organized, e.g. in the field of quality control of aquatic environments between the ordering parties responsible for monitoring the quality and the laboratories they employ to take samples and analyze them, which might be public or private.

Ordering parties have their own specific information systems to match their particular information management requirements. As a result, it was difficult for these organizations to exchange specialized information.

The national standardization system for data exchange, called “EDILABO”, was set up by Sandre with the support of a group of experts in order to:

- ❶ Adopt a common vocabulary used by all stakeholders so that they can understand each other using specialized terminology;
- ❷ Choose the specialized information that stakeholders wish to exchange to carry out quality controls in aquatic environments and to make samples and analyses;
- ❸ Create a single code for some key data, such as parameters measured, for all stakeholders and use it to create a shared repository;
- ❹ Choose a specific syntax to format specialized information so that it can be exchanged.

Thanks to this standard, in 2017, several thousand results of analyses of physico-chemical and microbiological parameters relating to the quality of aquatic environments were able to transit between different information systems and stakeholders.

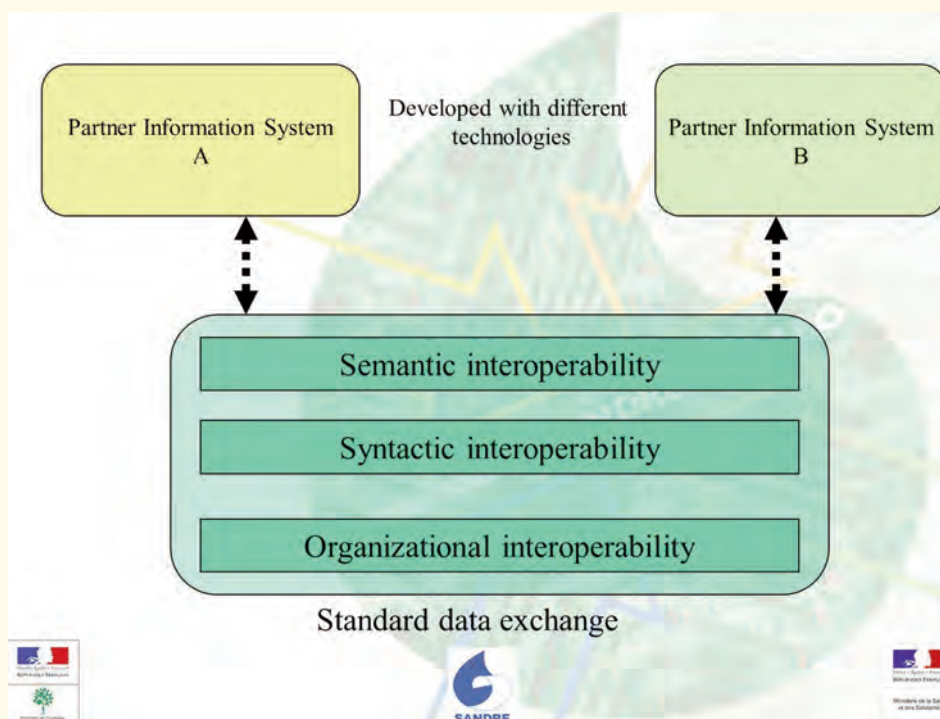


Figure 21: Levels of interoperability to consider

Case study 13: The La Plata River Basin [21]

The La Plata basin, with an area of 3,200,000 km², is the second largest catchment area in South America and one of the largest in the world. It covers large territories belonging to Argentina, Bolivia, Brazil, Uruguay and Paraguay. To facilitate access and exchange of hydrological data provided by the National Hydrological Services of the Plata basin, CHy supported the development of a technical solution, called PLATA-HIS (see *LaPlataHIS.pdf* [43]). The aim was to provide additional operational capability, in particular for in situ water observations, as a federated resource for National Hydrological Services.

Using a combination of WMO and OGC web services, the PLATA-HIS (<http://hydrolite.ddns.net/hisPlata/>) is designed as a “service stack framework” that identifies three types of services as essential to sharing hydrological information across the web: catalogue services, metadata services and data services. These three services work together to completely index, describe and provide access to hydrological time series in the La Plata river basin.

The system has been successfully used as follows: definition of a monitoring network of hydrological and meteorological stations maintained by countries belonging to the La Plata basin; analysis and optimization of the hydrological monitoring network at the basin scale; increased collaboration between countries to improve network design and lower costs; collaborative calibration of hydro-meteorological instruments; free exchange of meteorological and hydrological observations; common policies to control data quality; and creation of archives of hydrological data to improve services and respond faster to natural disasters.



Figure 22 : Discovery and access of hydrological data in La Plata basin

Case study 14: The Arctic-HYCOS [21]

Sharing information and knowledge among NHSs and international projects promotes a consolidated approach to studying the freshwater flux to the Arctic Ocean and Seas and furthers our understanding of the Arctic hydrological regime and related climatic variability and change.

The Commission for Hydrology supported the implementation of a hydrological observation system within the Arctic drainage basin known as Arctic-HYCOS (see ArcticHycos.pdf [44]). The Arctic countries of Canada, Denmark, Finland, Iceland, Norway, Russian Federation, Sweden and the United States are participants in the Arctic-HYCOS project, and they freely and openly share all data and metadata from stations within the project network with all project participants, following Resolution 25 (Cg-XIII) on the Exchange of Hydrological Data and Products.

The Arctic-HYCOS project provides a platform (<http://hydrolite.ddns.net/hisArctic/>) for the regular collection and free exchange of Arctic hydrological data. Project activities also include evaluating, maintaining and potentially upgrading existing observation stations. Network analysis identifies observation stations suitable to evaluate freshwater flux into the Arctic Ocean and Seas and to study changes in Arctic hydrological regimes relative to climate change.

The development of the system in support of standardized data exchange allows: international cooperation to study and assess hydrological processes in the Arctic, in particular related to climate change; reliable assessments of freshwater flux into the Arctic Ocean and Seas both in the short and longer terms; a better understanding of links between Arctic river discharge, the freshwater balance of the Arctic Ocean, thermohaline circulation, and the global climate; improved water management enabling better stream flow monitoring and prediction of hydrological changes thus improving life support systems in polar communities; hydrological data to be contributed to other Arctic Observation Systems, in particular to research groups and monitoring programs dealing with Arctic snow hydrology, permafrost, glaciers and glacial runoff; and hydrological data to be contributed to Global Observation Systems, in particular WIGOS.

WHOS
WMO Hydrological Observing System

You have gone full screen [Exit full screen \(F11\)](#)

[Home](#) [Services](#) [Tools](#) [About](#) [WMO](#)

ARCTIC Hydrologic Information System Central Web Service Registry

The Arctic-HYCOS program is being promoted through the World Hydrological Cycle Observing System (WHYCOS). The main goal of the Arctic-HYCOS program is to improve monitoring, data accuracy, availability and dissemination of information in the pan-arctic drainage basin. This project is science-driven and is aimed at monitoring freshwater fluxes and pollutants into the Arctic Ocean with the objective of improving climate predictions in the Northern Hemisphere and assessing the pollution of the Arctic coastal areas and the open Arctic Ocean.

The portal provides access to the hydrological observations in the Arctic monitoring network, composed of stations located in Canada, Denmark, Finland, Iceland, Kazakhstan, Mongolia, Norway, Russian Federation and United States of America. In particular, the portal provides additional operational capability, for in situ water observations, as an international registry of water data services catalogued using the standards and procedures of the Open Geospatial Consortium and the World Meteorological Organization.

The published interfaces of the portal retrieve data from distributed national water data providers, enabling plots and download.

WEB SERVICE REGISTRATION SYSTEM

- Brokered services: 12
- Brokered sites: 5191
- Brokered variables: 1
- Brokered values: 597973
- Geographic extent: [-178.67, 179.24, 45.82, 80.0]

Figure 23: The Hydrological Information System in the Arctic-HYCOS project

Case study 15: UNESCO Water Family [9]

Created in 1975, UNESCO International Hydrological Programme (IHP) constitutes the only intergovernmental programme of the UN system devoted to facilitating water research, water resources management and governance, and education and capacity building.

In this endeavor, the IHP benefits from the support of the UNESCO Water family, which constitutes an extended network of water professionals based in water related Ministries (IHP National committees), universities, institutes and research facilities directly linked to IHP's programmes in order to serve its Member States and build scientific knowledge. This network is composed of 168 IHP National Committees and focal points among UNESCO's 195 Member States, 48 water-related chairs (interested universities around the world, aiming at bridging the knowledge gap) and 36 regional centres and institutes (working on relevant thematic and geographic priorities in their areas of expertise, under the auspices of UNESCO).

In January 2017, the IHP launched its Water Information Network System (IHP-WINS), an open-access, cooperative and participatory web platform that incorporates geospatial data on water resources into a database to foster knowledge sharing and access to information. IHP-WINS allows gathering and disseminating information and knowledge developed by the UNESCO Water Family and other stakeholders.

IHP-WINS acknowledges that in order to build a strong spatial data infrastructure, metadata is crucial. As a result, in addition to supporting standard data formats, the platform also supports standard metadata representations. Metadata and metadata servers enable users to integrate data from multiple sources, organizations, and formats. On IHP-WINS, metadata for geographical data include the data source, its creation date, format, projection, and additional information such as the source, author, an abstract, a quality statement, and point of contact. Metadata on IHP-WINS build on the GeoNode 2.6 Metadata. Services enable users to create a central, online metadata repository that facilitates publishing and browsing metadata over the Internet.



Figure 24: The-UNESCO-Water-Family-network

3.4 Data processing, information production and visualization

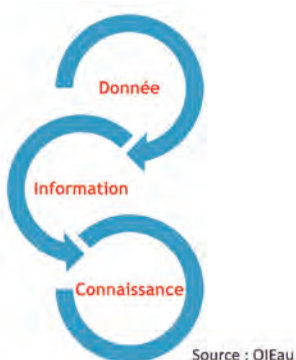
KEY POINTS:

- Raw datasets should be processed and transformed into information in a format that can be understood and used by decision-makers and answer the expectations of final users.
- Many tools, from spreadsheets to modelling software, are available for data processing.
- Processing tools and the way the information is presented should be adapted to match requirements using an ad hoc visualization mode and ad hoc communication support.

3.4.1. Water data processing and analysis

If raw data are not processed, presented in a format that can be understood and used by decision-makers, then access to data will not make a difference, even if available in large amounts.

The main objective of a “data processing/ information production” phase is to transform raw data into understandable information that corresponds to requirements and to the target public.



■ **Data** = Direct result of a measurement, not interpreted;

■ **Information** = Set of data processed, formatted and interpreted, to which a meaning is given;

■ **Knowledge** = Result of a reflection on the analyzed information.

The standard methodology related to this phase generally includes: [17]

- Identification of information needs: information for whom, for what, in what format, etc.;
- Identification of how to present the information and the communication support ;
- Identification/quality control of the available datasets and cleaning: consistency check, possible correction, etc;
- Data processing: exploitation (calculations, cross-referencing, etc.);
- Analysis: interpretation of the results;
- Enhancing: formatting, attribution of a meaning;
- Dissemination and communication.

Metadata catalogues help to identify the existing datasets and check if their characteristics correspond to the needs.

A broad range of tools is available to assist data analysis and processing. The various types of tools used for data processing include:

- Spreadsheets and databases;

- Database management tools;
- Geographic information systems;
- Tools for statistical data analysis, data mining (making predictions and decisions on the data you have at hand);
- ETL (Extract- Transform- Load) tools;
- Modelling tools;
- etc.

Box 16: About water resource modelling – World Bank [45]

The Modern Data and Tools for Integrated Watershed Management e-book prepared by the World Bank [45] underlines that modelling is a way to simplify the processes of reality to better represent the state of current knowledge in terms of inter-relationships across variables. In the context of a watershed, modelling can be of many types, including:

- **Water Balance/Hydrologic Modelling:** Accounts for what happens to the hydrologic cycle elements of a watershed in terms of rainfall, evaporation, transpiration, surface flow, infiltration, outflow, etc. in both a pristine watershed and as influenced by anthropogenic factors such as storage, pumping, use, discharge, etc.
- **Hydraulic/Hydrodynamic Modeling:** These tools of varying complexity explore flow in channels and flooding.
- **Water Quality Models:** These models help explore pollution sources for various pollutants and explore the fate and transport of these pollutants and their implications on the water quality of the streams and further downstream receiving bodies of water.
- **Limnology Models:** These explore the way lakes behave in more detail.
- **Erosion Modelling:** These generally use some version of a Universal Soil Loss Equation that models potential erosion based on information such as topography, soils, precipitation, landcover, and land management.
- **Other Specialized Modelling:** Watershed modelling can also include very specialized models related to groundwaters/aquifers, energy systems, specialized economic modelling (e.g. game theory), etc.
- **Water Systems Modelling:** These usually use either simulation or optimization to look beyond single “projects” such as dams, irrigation command areas, hydropower plants, water supply, etc. and explore these in a larger inter-related systems context (e.g. as a watershed, sub-basin, basin, etc.). Some of these models only address bio-physical aspects, but others extend this to include economic, environmental, and social aspects.
- **Decision Support Systems:** These are more integrated approaches to support water resources planning (e.g. watershed investment planning) or real-time systems operations (e.g. cascade of dams, flood management). It is critical to note that these are not decision-making systems, but provide information to support decision-making where the appropriate stakeholders bring in the value judgements of the synergies and trade-offs involved with various alternative decision paths.

3.4.2 Transforming datasets into useful and understandable information: dashboards, indicators, maps, graphs, etc.

"A picture is worth a thousand words", Confucius

With the rise of digital culture and information and communication technologies, datasets have multiplied but are sometimes too complex to be fully understood and shared. Ad hoc methods to visualize and present information should be adopted to make information easy to understand and adapted to its audience.

Data visualization is a visual representation of data, which can take the form of a graph, map, chronology, hierarchy, video, animation, etc. It aims to make figures easy to understand in a creative, understandable and easy way. Combining simple functions and aesthetics, it represents a powerful analysis and communication tool. And it can

Case study 16: FREEWAT: FREE and open source tools for WATER resource management [9]

In partnership with 18 universities, centres and other organizations, UNESCO-IHP is collaborating on the FREEWAT project (<http://www.freewat.eu/>), a HORIZON 2020 project financed by the EU Commission. The project adopts an innovative participatory approach gathering technical staff and relevant stakeholders, including policy and decision-makers, to design scenarios for the proper application of conjunctive water policies [46].

FREEWAT's main result is an open source and public domain GIS-integrated modelling environment (the FREEWAT platform) for the simulation of water quantity and quality in surface water and groundwater with an integrated water management and planning module. FREEWAT is a composite plugin for QGIS, designed as a modular ensemble of different tools, including for analysis, interpretation and visualization of hydrogeological and hydrochemical data and quality issues, for simulation of models related to the hydrological cycle and water resources management, or for performing model calibration

The consortium also organizes capacity-building workshops and seminars. So far, a total of 890 individuals had to be trained to use the platform within the EU, 60 in Switzerland, 100 in neighboring countries (Ukraine and Turkey) and another 80 in Africa (South Africa, Namibia and Botswana).

A new version of the FREEWAT plugin (v.1.0) has been available since 17 October 2017, and can be downloaded, along with a complete set of up-to-date User Manuals and Tutorials, through accessing the *Software -> Download area page of the FREEWAT website*.

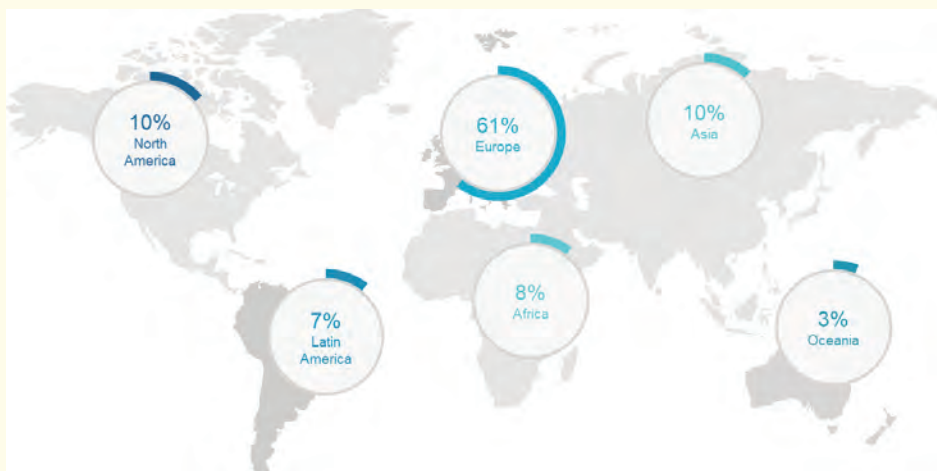


Figure 25: Percentage-of-FREEWAT-downloads-per-Continent

incorporate interactive capabilities that allow users to explore and "play" with the data.

Thanks to their capacity to enhance the impact of data and make them easier to understand, visualization solutions constitute a critical component in the production of information. As a result, decision-makers and water stakeholders can easily see what it is important to focus on, and adapt their policy-making in accordance.

Dashboards, indicators and maps are the most typical types, comprising advanced analysis and easy-to-understand data visualizations that can help data users to see patterns, trends, or correlations that might go undetected in text- or number-based data.

When providing a water information system with a data visualization tool, good quality is essential to ensure that it is sustainable. Data quality is essential, because if users realize that they cannot trust data to help them make decisions, they may stop using the tool [47]. However, the quality of data visualization should also be taken into account. Presenting the

information by using the wrong type of visualization will result in a misleading representation and outcome that may hinder smart decision-making. The most appropriate way to present information should be chosen based on a reflection around (i) the understanding of the data and its composition, (ii) the function of the data and the information that should be conveyed to the audience, (iii) how viewers navigate and interact with the data [48].

The main types of presentation include:

- **Indicators and dashboards:** An indicator can be raw or elaborate data. It comprises concise information intended for a particular use (e.g. monitoring of public policies). Indicators can be presented as graphs and can be grouped together in a dashboard;

- **Maps** are among the most common communication formats in the water sector: produced using GIS, they clearly show the geographical distribution of the various phenomena to be analysed;

- **Key figures** are also useful for communication. They are produced from dataset processing or document and website content analysis. The goal is to make the figures understandable for as many people as possible;

- **Summary documents** allow beginners to learn more about a subject and professionals to update their knowledge;

- **Newsletters** are also very useful to provide regular information on specific topics.



Figure 26: Example of publication on the price of water in France

3.5 Information dissemination/sharing knowledge

KEY POINTS:

- Many channels and digital tools can be used for information dissemination in complement to paper information dissemination.
- Defining an appropriate strategy of communication adapted to the need and using the ad hoc tools is recommended.

3.5.1 Tools and methods for disseminating information

Many channels and various supports of information can be used for disseminating and sharing knowledge.

The media and representation modes vary depending on the target audience and the kind of information to be disseminated.

To relay reliable information that corresponds to the needs of the audience involves defining an appropriate strategy.

Some tools for digital information dissemination are described below, bearing in mind that in many cases complementarity should be insured with the dissemination of information on paper.

Web portal / Website

Once collected, verified and stored, datasets and information can be disseminated on portals or websites.

Web portals are useful for coordinating communities of actors by pooling and disseminating knowledge (centralizing data on sub-basin management plans and environmental contracts, publication of news related to water management and newsletters, provision of documents); gathering, sharing and highlighting experiences (forums, records, themed sections); and supporting actors and helping to build skills (dissemination of guides and studies, organization of web-conferences).

The portals or websites generally adopt the principles of responsive design, offering visitors a comfortable consultation whatever the medium used (smartphone, tablet or computer). Coupled with an efficient search engine, access to resources is made easier. The addition of interactive maps can also facilitate access and sharing of information, experiences and geographical searches for local and international action (depending on the case).

Smartphone Apps

Smartphone applications are highly popular, even in the field of water. Free applications can identify various targets that require reactivity and interactivity. Smartphone applications can transmit geolocated data that bring users information close at hand.

E-book

Dissemination linked to documentary tools has also changed significantly over the years. Initially, technical documents relating knowledge of current water issues (climate change, integrated management of coastal waters, hydro morphology, etc.) were published and then promoted.

Thanks to research and technological innovations, international water documentation portals such as "Eaudoc" (www.oieau.fr/eaudoc) now provide accessible search engines with an easy-to-use documentary interface and varied content.

In parallel, enriched digital books make it possible to explain a subject in an educational,

interactive way (e.g. on sub-basin management plans, available online at <http://www.oieau.fr/eaudoc/ebooks/sage/>). This kind of support goes beyond linear reading, thanks to the possibility of accessing all topics from each page and linking different pages. The pages are organized so that important information is directly accessible; users can then find out more details by interacting with various media, e.g. dynamic opening of text blocks, videos, audio recordings, maps and slideshows.

Social networks

While portals, websites and applications serve to showcase projects, social networks also play an important role in disseminating information.

Social networks contribute in particular to bringing Internet users to a website, relaying communication operations, publishing information, and efficiently reinforcing web indexing, etc. These networks are interesting tools to establish special contact with Internet users, create a community, and raise awareness among a wider public who are unlikely to directly visit the website.

Most importantly, publishing information on social networks can be a way to transmit news better. As an example, to relay messages efficiently on the web, IOWater uses several social media (Twitter, Facebook, LinkedIn, Youtube, Pinterest) that have their own characteristics (promotion of videos, images, etc.).

3.5.2 Case studies

Case study 17: Ma Conso [17]

“Ma Cons’eau” is a free application that allows you to estimate your water consumption and the impact of savings on your bill.

By answering a series of simple questions, My Cons’eau assesses your annual consumption.

The estimated amount of your water bill is calculated based on the price of water in your municipality.

Your municipality is determined by geolocation or by choosing from the list of French municipalities.

The price is determined by:

- identifying the price for your town on the Internet,
- or the average price in France if the price for your town is not found,
- or the price indicated on your invoice that you enter into the application.

Finally, tips are provided to reduce consumption per item of expenditure, with an evaluation of the impact on the overall bill.

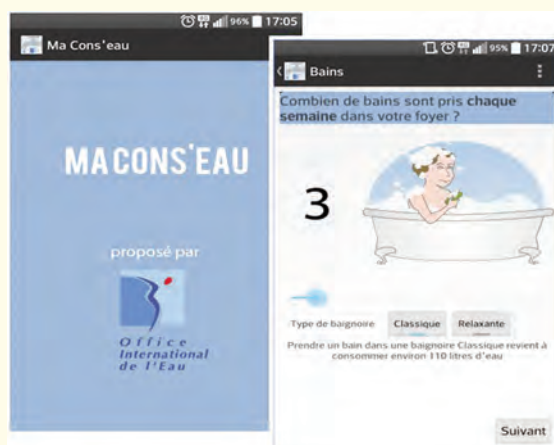


Figure 27: Ma Conso Application

Case study 18: The Water Information Network System platform (IHP-WINS) [49]

UNESCO-IHP is behind the Water Information Network System (IHP-WINS), which was launched in January 2017 [49]. This online platform (available at: <http://ihp-wins.unesco.org/>) incorporates geospatial data on water resources into a cooperative and open-access participatory database to foster knowledge-sharing and access to information. IHP-WINS is freely made available by UNESCO-IHP to Member States, water stakeholders and partners with the aim of facilitating access to information, and encouraging contributors to share data on water. Thanks to these contributions, the platform benefits from continuous enrichments with spatial data and documents, coming from various sources. A variety of spatial data is shared and accessible on the platform: the scale varies from worldwide to very local level, information can be quantitative or qualitative, and both raster and vector files are available. Additionally, because the platform is open to a variety of contributors, information covers a large array of water-related topics ranging from quality to risk, and gender, etc. Users can combine these layers of information to create maps tailored to their own needs.

Transparency and respect of authorship is guaranteed as all information provides the benefits of metadata in a standardized format from a Digital Object Identifier (DOI: 10.29104). This allows for accurate identification and crediting of all contributions, and facilitates later sharing. Inter-disciplinary collaboration, professional networking and mentoring are also stimulated through

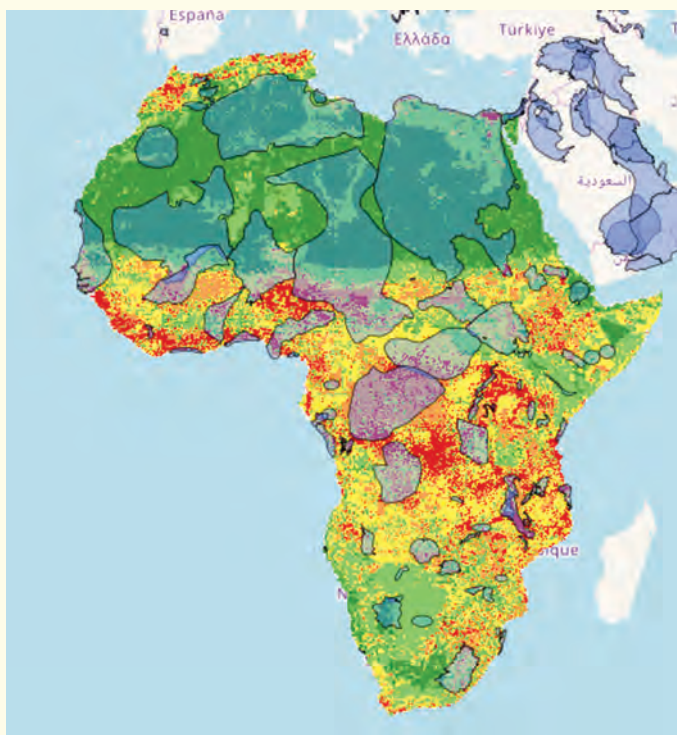


Figure 28: IHP-WINS map overlaying transboundary aquifers to groundwater pollution risk data

working groups where users can exchange and provide feedback on their ongoing work. This involvement and participation contribute to the building of an online community. By gathering global and inclusive knowledge on water, and facilitating interdisciplinary collaboration, IHP-WINS aims overall at supporting Members States and stakeholders involved in resource management. The platform will also contribute to close the gap between North and South in terms of access to knowledge. The initiative contributes to the follow-up on the monitoring and implementation of the targets of Sustainable Development Goal 6 (SDG 6) and those of other water-related goals.

Case study 19: France/ Gest'eau [17]

The Water Development and Management Plan (SAGE) is a planning tool established by the Water Act of 1992, which aims at balanced and sustainable water resources management. This is a local variation of the Master Plan for Water Development and Management (SDAGE), which sets out the fundamental orientations of water policy in major French river basins.

The SAGE establishes, coordinates and prioritizes general objectives for the use and protection of water resources, taking into account the specificities of the territory. It determines priorities for action, identifies the resources needed, and lays down rules for the sharing of uses. Based on a voluntary approach, it has proved an effective tool for responding locally to the objectives of the Water Framework Directive (WFD), especially the objective of good status of water bodies.

To promote the balanced and sustainable management of water resources and aquatic environments and federate stakeholders, IOWater is responsible for facilitating the network of SAGE stakeholders and environment contracts. The objective is to meet the needs of local stakeholders, taking into account the national priorities of the water policy and its links with the biodiversity policy, the flood directive, its integration into land use planning and economic development policies, as well as its part in territorial reform.

Since 2002, IOWater has been facilitating the network of stakeholders in local water management, especially through **Gest'eau**, by pooling and disseminating knowledge, gathering, sharing and enhancing experiments, accompanying stakeholders, and building capacities.



4 MAIN DOMAINS OF APPLICATION

MAIN KEY POINTS

- Various forms of water information systems (WIS) exist depending on their domain of application: IWRM, CC adaptation, flood or drought management, sectorial management, etc.
- Whatever the domain of application, a modern and integrated WIS requires organizing access to data through various data sources, which in turn requires inter-institutional coordination/cooperation between stakeholders.
- Water information systems include various functionalities depending on the domain of application.

4.1 Integrated Water Information Systems for IWRM and planning at basin and national levels

KEY POINTS

- IWRM requires pooling multiple data produced by various organisations to develop and share knowledge.
- The available datasets are firstly quality controlled (metadata) and then used to prepare maps and indicators, necessary in particular for basin characterizations, defining programmes of measure and monitoring action.
- Stakeholders should have access to data and information in ways which suit their needs through national and basin integrated water information systems.

4.1.1 Stakes and data/information needs for IWRM

Integrated Water Resources Management (IWRM) requires pooling multiple data to develop and share knowledge, learn to work together, and establish a degree of cross-functionality between stakeholders. A good knowledge of water resources is a preliminary, but not so easy, first step. Combined with simple socio-economic information (population, land use, agricultural activities, etc.), it can be used to identify the impact of human activities and pressures on water resources.

The absence of exhaustive data or lack of data should not be used as a pretext for delaying action. While rarely available at the watershed scale, data should be collected by the smallest possible administrative unit to facilitate subsequent manipulation at sub-basin scale, and over a longer period to estimate trends.

To characterize a river basin, the main data to be collected if possible are as follows:

- Background: topography (slopes, relief); geology; land use;
- Resources: river basin boundaries; hydrographic context (streams, canals, bodies of water, estuaries, coastal waters, wetlands); extension and type of aquifers;
- Monitoring points and results (rainfall, river flow, reservoir level, quality, groundwater level);
- Administrative limits;
- Pressures: distribution of the population; distribution, type, needs and discharges of industrial, mining and artisanal activities; management of wastewater; distribution of

hydropower plants; distribution and typology of agricultural activities (irrigation, crops, livestock, fertilization, plants protection);

■ Hazards and risks: sensitive uses (withdrawals for drinking water, aquaculture, bathing); flood areas; protected areas; distribution and typology of water-related diseases.

The data are initially presented on thematic maps to provide a strategic, original and meaningful vision at river basin scale. These maps give an initial idea of the hydrographic territory. Maps are also useful to record stakeholders' visions and perceptions. These subjective elements should be compared with objective elements from specific diagnoses and surveys.

Box 17: Main principles of IWRM

To ensure that IWRM is efficient and beneficial to all users, it is recommended to build it around 6 main principles (see below).

- ① Water resource management should be organized and discussed at the geographical level to determine whether problems occur at local, national or transboundary river basin, river, lake or aquifer level;
- ② **It should be based on integrated information systems defining the resources and their uses, pressure from pollutants, the ecosystems and how they work, risk identification and monitoring of trends. These information systems should constitute an objective basis for discussion, negotiation, decision-making and action assessment, as well as for coordinating financing from the various funding sources;**
- ③ It should be built around management plans, or master plans, setting the medium and long-term objectives and shaping a common vision of the future;
- ④ It should provide for successive, multiyear, prioritized action and investment programmes, according to the financial resources available;
- ⑤ It should mobilize specific funds, in particular based on application of the "polluter pays" principle and "user pays" system;
- ⑥ It should allow for participation in the decision-making processes by the local authorities concerned, representatives of the various user categories and environmental protection associations or those working in the public interest, alongside the competent government departments. Through a process of discussion and consensus, it is this participation that will guarantee the social and economic acceptability of the decisions reached, by taking account of the real needs, level of acceptance, and social and economic stakeholders' ability to contribute. Decentralization is key to water policy effectiveness.

This comparison also leads to the production of orders of magnitude adapted to each local context. This magnitude knowledge can be used to verify, enhance, compare and criticize (e.g. specific flows, fertilizer inputs per hectare, population density, theoretical pollution flow per unit area, specific concentration, etc.).

Complex exploitation of data (e.g. modelling) may initially frighten decision-makers and stakeholders daunted by the prospect of information understood only by experts. For this reason, it is necessary to build ownership and to involve stakeholders into the modelling process.

Sharing data from all sectors is a necessary step in IWRM. It is a way of identifying the actors concerned to different degrees by the water resource, and can be used to initiate dialogue, exchange and coordination.

Many actors consider that it is more economical to share data for free than to sell them.

Depending on the objectives of the River Basin Management Plan, evaluation data should be robust because they can involve substantial investments. For example, the selection of the lowest bidder for biological indicators may prove to be very expensive.

Evaluation data help to guide actions, communicate results, test out the strategy, and monitor compliance with rules and standards.

Case study 20: Australian Water Resources Information System (AWRIS) [8]

The Bureau of Meteorology has responsibility for collecting, holding, managing, interpreting and disseminating Australia's water information. Given this mandate, the Bureau developed the **Australian Water Resources Information System (AWRIS)** to receive and manage water data and related information, and to support the production and dissemination of a variety of water information 'products' and services. AWRIS is designed using a conventional best-practice 'data warehouse' architecture. It has an 'ecosystem' of interdependent system components delivering Australia-wide water information services and products to industry managers, policy-makers, scientists, farmers and the general public. The AWRIS Ecosystem is capable of processing daily over 15,000 incoming water data and metadata files from 178 water data providers (DPs) across Australia. The ecosystem captures incoming files, performs validation functions and ingests data to the AWRIS data warehouse. The data warehouse holds over 4 billion observations (growing by approximately 500 million per annum) including streamflow, storages, water trading and markets information. A Data Flow Console provides a range of management functions to control and monitor the flow of files through the Ecosystem.

The Time Series Data Management component of the Ecosystem holds all time-series data enabling online access for customers and quality control, as well as being the source of truth to downstream Data Marts and to the Water Data Online product. Data Marts provide well-structured data views which together with the Web Map Services enable dashboards for online Water Storage and Water Market products as well as a plain text website.

The diagram illustrates the AWRIS ecosystem architecture, showing the flow of data from sources to various products and services. The process is divided into several stages:

- Sources of Data (178 Water Organisations):** Data Providers Quality & Coverage. Includes categories like CAT1 (Surface Water), CAT2 (Groundwater), CAT3 (Water Use), CAT4 (Meteorological), CAT5 (Urban Water), CAT6 (Water Resources), and CAT7 (Water Quality).
- Incoming Data Channels:** Email, FTP, PC File, Media.
- Package and File Registration:** Registration process involving File Registry DB and ICDT Validator.
- Ingest Queue Management:** Ingest Queue, Unpack Formats, Verify Reference Data and Metadata, Error Processing.
- Data Warehouse:** Staging, Ingest Logic, Integration, TimeSeries.
- Data Extraction from Data Warehouse:** Water Markets Data (CAT7), WADI, WADI.
- Other Data Mart Sources:** ACSI Data, Titled ETL, Meta Data Edit, AWRIS/ETL Interface.
- Dedicated Data Marts:** Water Data Marts - Storages - Markets, WADI, TSM (APIs and Client), WADI (CAT1 & CAT2), ETL, Storage Applications.
- New Products:** Storages Phone App For iOS and Android, Tableau Dashboards (Storages Dashboard, Markets Dashboard), Water Data Online, FloodRisk.

The diagram also includes a **Data Flow Console** at the bottom, which tracks file status from receipt to load complete. The **Ecosystem Management** section is located on the left side of the diagram.

Figure 29: AWRIS ecosystem

Case study 21: Lao Water Information System (LaoWIS) [50]

LaoWIS is the first Water Information System (WIS) in Lao PDR and is developed by the Department of Water Resources of the Ministry of Natural Resources and Environment (DWR-MoNRE) with the support of French technical assistance. The water-related database LaoWIS aims to develop tools and scenarios to share useful data for IWRM among data producers/ managers/ users. The revised Law on water and water resources (2017) introduces the concept of a "National Water and Water Resources Data and information System" for the first time. It specifies that the MoNRE is responsible for collection, compilation and establishment of the national system of the data and information, and for the use and supply of water and water resources in connection with the National Statistic Information Centre and the relevant ministries and local administrations.

LaoWIS is managed by the data team of the DWR-MoNRE and their first project involved gathering data from the 7 divisions of the DWR-MoNRE and inputting them into the database. With the current data available, the team has begun to develop some tools to share information on their web-portal, such as webmapping, reports about water status in Lao PDR, and a basin atlas gallery.

In conformity with the DWR-MoNRE mandates, the short-term plan is to develop an online water assessment tool and to reinforce data exchange with:

- The line agencies at provincial level - PoNRE (starting with 3 provinces),
- The Department of Meteorology and Hydrology (DMH-MoNRE) which produces meteorological and hydrological data at national level.

Considering the high number of dams in Lao PDR, the next step will be to add data from the energy sector into this sharing process, especially to acquire information about dam releases to boost water allocation knowledge. A sharing process could be developed with the Ministry of Energy and Mines (MEM), which has information about dams.

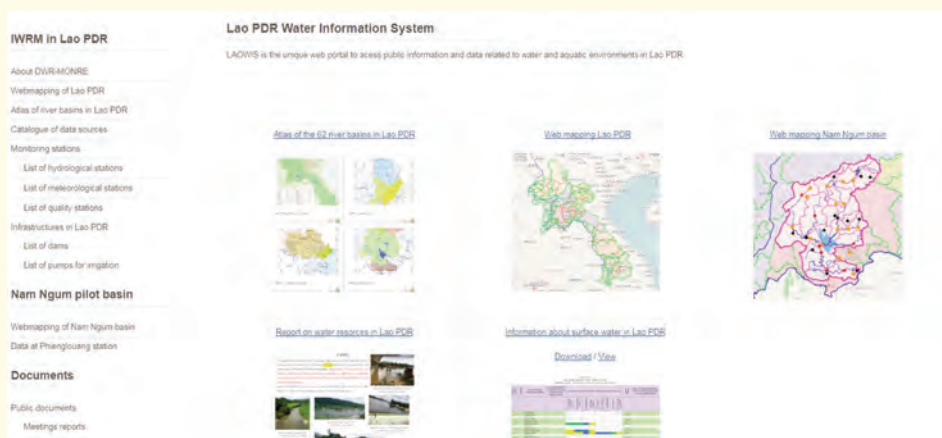


Figure 30: Some functionalities available on the LaoWIS Portal

Case study 22: French Water Information System (SIE) [14]

The French Agency for Biodiversity (AFB), created by the law of 8 August 2016 and the decree of 26 December 2016, has been operational since 1 January 2017. In mainland France and overseas, the agency contributes to the preservation, management and restoration of terrestrial, aquatic and marine biodiversity, the development of knowledge, resources, uses and ecosystem services related to biodiversity, the balanced and sustainable management of water, and the fight against biopiracy. Establishing reliable and shared data is a major challenge for these missions.

The AFB provides technical coordination of the information system on water, aquatic environments and public water and sanitation services. Along with its partners and territorial services, it designs and implements observation and evaluation systems for terrestrial, marine and aquatic environments and their uses. It is also responsible for the technical coordination of the biodiversity information system, including the Water Information System (WIS), the Nature and Landscape Information System, and the Marine Water Information System. It ensures their consistency and works to promote sharing and dissemination of data and indicators, particularly via the information services Eaufrance and Naturefrance.

In France, the purpose of the Water Information System (WIS) is the collection, conservation and dissemination of data and indicators on water, aquatic environments, their uses and public services on water distribution and sanitation. It comes under the National Scheme of Water Data (SNDE). The SNDE is supplemented by technical documents, some of which are produced by SANDRE, and must be respected by all WIS contributors in accordance with Decree No. 2009-1543 of 11 December 2009. The state establishes the elements of the data repository that must be used for the purposes of application of the regulations, and the conditions of their use.

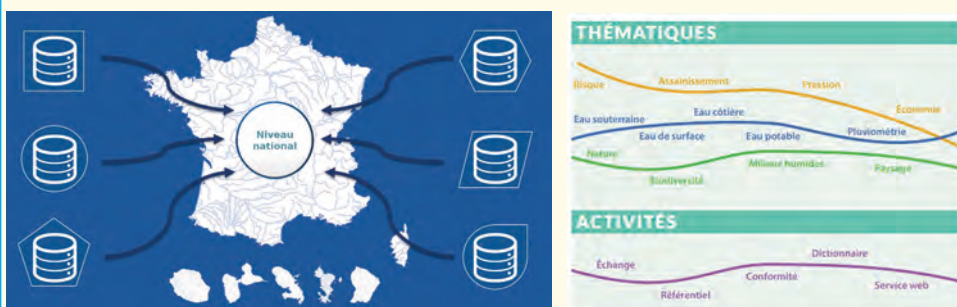


Figure 31: Topics of the French Water Information System

The WIS comprises:

- Reference data;
- Data produced by observation and other environmental devices (surveys, declarations, reports, administrative acts, etc.);
- Elaborated data.

Case study 23: Water Information System Construction Achievement, Haihe River Water Conservancy Commission (HWCC), Ministry of Water Resources of China [51]

In recent years, based on the Chinese government's requirement to promote the modernization of water conservancy through informatization, the water authority in charge of the Haihe River Basin, Haihe River Water Conservancy Commission (www.hwcc.gov.cn) has built a basic integrated water information system consisting of an infrastructure, an application system and a support environment. The system has provided significant technical support for flood and drought control management and water resources management in the Haihe River Basin.

Service Area	Application Field
Flood and Drought Control	Flood forecasting, regulation, assessment, drought management, engineering operations, flood risk map, etc`
Water Resources Management	Water resources information service, emergency management, regulation decision-making, remote sensing information, law enforcement inspection, etc.
Hydrology	Rainfall information enquiry and management, monitoring and report information system, etc.
Water and Soil Conservation	Water and soil conservation monitoring data management system
Rural Water Conservancy	Rural water conservancy management system
Science and Technology	Water conservancy science and technology sharing system

For the next step, HWCC plans to introduce a new informatization concept and technology to integrate information resources, improve networks, build a data centre and unify its portal. It will attempt to build an HWCC integrated water conservancy management platform with “one network, one map, one centre and one portal”.

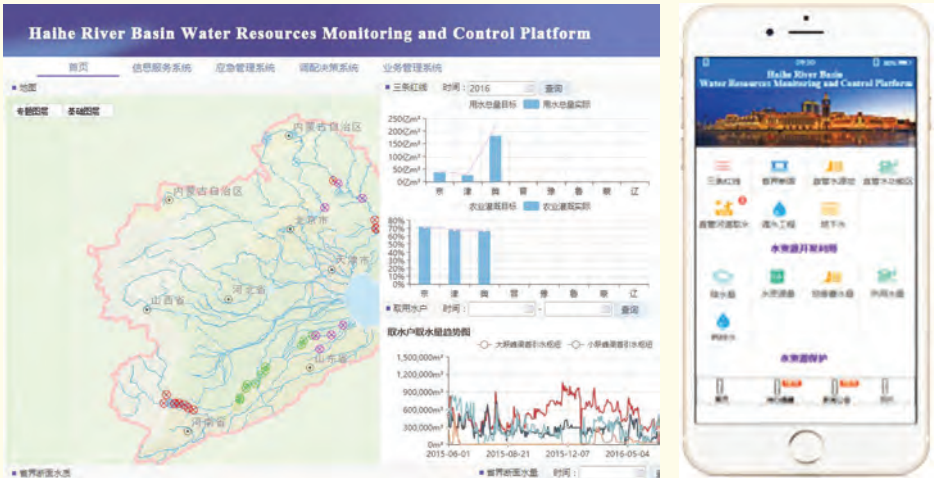


Figure 32: Haihe River Basin Water Resources Monitoring and Control Platform and Mobile APP

(Cont'd)



Figure 33: Haihe River Water Conservancy Wechat Public Account

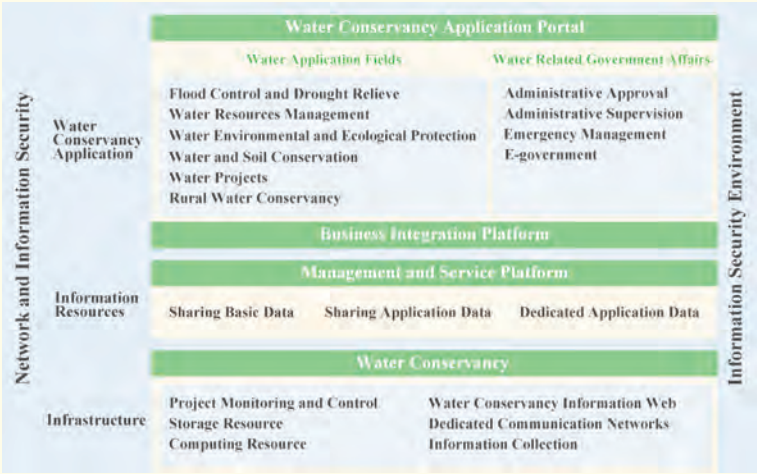


Figure 34: Main Framework Chart of HWCC Water Conservancy Informatization Development

Case study 24: Water Resources Assessment (WRA) [21]

WMO is developing the Water Resources Assessment (WRA) project.

Water Resources Assessment is more than conducting a simple water balance, it requires a dynamic approach to the spatial and temporal variability of resources, and of demands and pressures put on them by various societal requirements (water supply, industry, agriculture, environmental protection, etc.).

WRA must support the provision of information and data to decision-makers enabling them to implement evidence and fact-based policies for both long-term planning to respond to short-term emergencies, based on the knowledge of status and trends of the resource.

WRA must also be flexible and adaptable to take into account the social, economic and environmental context, the skills and resources (human, financial) of the stakeholders (especially those involved in data monitoring and information generation), and the availability and quality of data. It is therefore important that they employ extensive consultative processes involving both users and providers of information to define requirements and the extent to which they can be satisfied

To support this broad interpretation of the WRA concept the whole value chain has to be addressed, from monitoring, to product development, to information delivery. In particular, existing WMO regulatory and guidance material refers to standards and recommended practices addressing several of the WRA process components, and the remaining gaps are being filled through the development of relevant material.

Case study 25: Mexico/ National Water Information System (SINA) [52]

SINA is the institutional system that integrates and provides the general public in Mexico with the largest amount of relevant statistical and geographic information on the water sector. It is an intuitive system, using a common language. It can be accessed over the web with a personal computer or any mobile device using standard browsers and can download report information and graphs in Excel and PDF format. It presents 492 thematic maps available for download in shapefile (shp) format.

The system is made up of people, data, information, material and computer resources, set up through a web consultation platform called SINA. This statistical and geographic system comprises 42 topics organized in three axes (environmental, economic and social); it has a module of technical sheets, using a Geosina geographic viewer, a glossary of terms, links to publications generated by system information, and links to a monitor of the daily level of dams and sites of interest, such as WMS services as well as social networks. Information from maps, tables and graphs can be downloaded free of charge.

SINA is an innovative statistical and geographic system since it integrates and publishes relevant information on the water sector, with a consultation interface, intuitive navigation, public access and easily understandable information for the general public, academics and specialists on the topic. The information can be viewed and downloaded in different formats (PDF, Excel and shp). It is a very useful tool for responding quickly to requests for information from different sources, including the National Institute for Transparency, Access to Information and Protection of Personal Data (INAI).

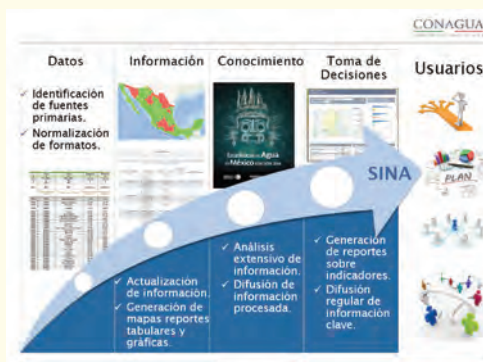


Figure 35: Main functions of the SINA

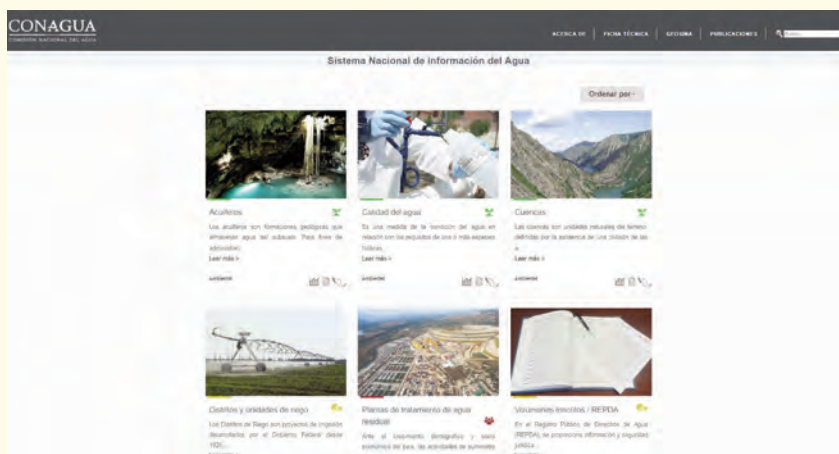


Figure 36: Welcome page of the SINA <http://sina.conagua.gob.mx/sina/>

Case study 26: Through an integrated management of knowledge on water in Quebec: case of water knowledge portal [53]

In Quebec, a large amount of data, information and knowledge related to water and aquatic ecosystems are produced and accumulated by various governmental and non-governmental stakeholders. However, this knowledge, although appreciable, is disseminated throughout these various organisms. In addition, it is not necessarily available or sufficient to support the information needs of good water governance. The MDDELCC1 Water Knowledge Bureau was therefore created to meet this goal and ensure that efforts are made to manage water knowledge more effectively and efficiently. Its mandates are defined in an Act affirming the collective nature of water resources and promoting better governance of water and associated environments.

One of the first commitments of the Water Knowledge Bureau is to create a Water Knowledge Portal (CEP). Its main objective is to support water stakeholders in the realization of their IWRM mandates by providing integrated, fast and transparent access to water knowledge while promoting its circulation, particularly through the provision of services, sharing, and collaborative work tools.

The ECP will include a collaborative platform and a geographic information management system.

It will offer different services and features, including:

- A common site to share and search for knowledge and expertise;
- Secure collaboration sites with different levels of accessibility;
- Blog creation services, forum, wiki, etc.;
- The creation of layers in geoprocessing extraction;
- The development of geoprocessing tools.

Ultimately, the target clientele will include several departments and agencies of the Government of Quebec and Canada, non-governmental organizations (NGOs), the research community, the municipal and aboriginal community, as well as groups of citizens recognized as key players in the field. The Water Knowledge Portal will be online in the spring of 2018.



Case study 27: Ecuador / Information to encourage participation [54]**# Basin council and integrated management of water resources: strong complementarity**

The Water Secretariat (SENAGUA), the governing body of water resources in Ecuador, is responsible for preparing the Public Water Registry, defined by the organic law of August 6, 2014.

Following the provisions of the same law, the necessary steps are being taken to establish the main works of watershed councils throughout the Ecuadorian territory, at the scales of the 37 local hydrographic planning units (UPHL) and the 9 Hydrographic Demarcations (DH).

The convergences between these two key axes of the integral management of water resources, which interconnect information systems and the participation of users in the basin councils, is central to SENAGUA's approach. To bring the two processes together, a computer sub-module was created, called "SI/GIRH", dedicated to basin councils within the framework of the National Information System.

The SI/GIRH platform in Ecuador

The country possesses numerous quantitative and qualitative data on water resources and uses. However, they are scattered, heterogeneous, and few are accessible in a standardized form as provided by various entities of national/decentralized level and by the water users themselves.

The "SI/GIRH" platform aims to facilitate access to data and information to encourage participation, planning, and good integrated management of water resources, with a friendly tool that can be used by all stakeholders. Developed with the technical support of IOWater, it aims to make data easy to access following simple, dynamic, flexible and economical procedures. In order to achieve these objectives, the "SI/GIRH" portal gathers information of national interest,

relating to demarcations and planning units based on a principle of participation. It also includes the work of SENAGUA and the councils in the planning framework (baseline maps, practical information). The dynamic character of the information is assured with web services, a geographic viewer and a catalogue of metadata that provides a comprehensive description of the data and information presented. The information made available is based on material produced by SENAGUA at central and local levels, applying the principle of subsidiarity, and also includes information available and produced by all actors in the sector.



Figure 37: Diagram showing how the SI/GIRH sub-module fits into the national water information system structure



Figure 38: Example of maps within Ecuador's SI/GIRH sub-module

4.2 Water information systems for climate change adaptation

KEY POINTS

- The water sector is particularly impacted by climate change; identifying adaptation measures supposes a capacity to regularly assess the vulnerability of water uses and ecosystems to climate change;
- Data collection should cover all aspects of the hydrological cycle, but also include data to characterize the present situation of water uses and the ecosystem, and to estimate the socio-economic impact of the changes;
- Adaptation to climate change requires a capacity to pool and process data produced by numerous stakeholders.

4.2.1 Challenges and data/information needs for CC adaptation

Water is the main driver of climate change, with significant impacts in many sectors, including agriculture, energy, fisheries, tourism, health and biodiversity. In addition to rising sea levels, climate change affects temperatures and rainfall patterns, impacting the availability of water resources available for its various uses and risks related to water (e.g. floods).

The need for integrated water resources management that supports the understanding of interactions among the different components of the hydrological cycle and the different projects and users places a greater burden on information suppliers. Information needs to be sufficient, relevant and intelligible for the various stakeholders in the different water-related sectors (e.g. navigation, hydropower, tourism, public health, agriculture, drinking water facilities). Thus a range of information is needed simultaneously, and has to be presented in different forms for different users.

Adaptation to climate change requires **a regular assessment of vulnerability** (water uses, ecosystems) in a continuous process and on the basis of relevant indicators for decision-making [55].

The quality of these assessments and the tools for monitoring national adaptation to climate change are "largely determined by the availability of data, the tracking and evaluation capability, and the country's ability to bring together producers and users of relevant climate information" [56].

It is recommended to rely on integrated assessments at the basin level (rivers, lakes and aquifers), given that impacts occurring in one part of a basin can be felt in other very distant parts.

As a consequence, access to comprehensive data at a general, national level across each basin is essential for identifying vulnerabilities and impacts, and developing adaptation strategies and scenarios, and "Collecting and sharing necessary data information and models concerning the entire water cycle must therefore be ensured".2

The process of specifying information needs should be based on an analysis of the water management issues related to climate change. Data and information needs should be defined for identifying:

- Potential effects of climate change on water resources under natural regimes;
- Requirements regarding the quality and quantity of water resources for specific uses (e.g. drinking water, irrigation, recreation) and functions of water resources (e.g. maintenance of aquatic life);
- Possible impacts on these uses and functions caused by climate change;
- Measures taken to address the impacts or improve the use or functioning of water resources, including environmental aspects (ecological status).

Adaptation strategies are based not only on data related to water management but also on socio-economic information and health hazards. Socio-economic information should help describe social vulnerability (e.g. risk maps “weighted” by population density, climate-dependent socio-economic sectors, health infrastructure and services, coping capacities). Health hazards may include factors that affect water quality (e.g. concentration of chemicals in water) and food safety, extreme weather events and changing meteorological conditions.

Box 18: About the Collaborative Risk Informed Decision Analysis (CRIDA) methodology [57]

Over the last two decades, climate system science has achieved remarkable advances in monitoring, modelling and predicting weather and climate, providing valuable information for decision-making. Unfortunately, a significant gap persists between the information available and the actual uptake by stakeholders. While climate science is reaching maturity in terms of how results are provided thanks to the coordinated action of the IPCC, on the stakeholder side no such framework has yet matured. This has led to an abundance of publicly available data and information on the potential impacts of climate change, such as the CMIP5 global circulation model outputs [57], but a lack of expert knowledge on the user side has limited the use of this information to effectively develop and implement adaptation strategies to climate change at the local level. This mismatch needs to be addressed in order for vulnerable water-stressed communities to benefit from the foresight provided by climate science. To assess how climate change can further aggravate the effects of water-related hazards, specific tools need to be developed to support decision-makers, analyzing the probability of the occurrence of adverse events under climate change uncertainty.

A recent methodology developed is Collaborative Risk Informed Decision Analysis (CRIDA), which provides the framework for a bottom-up approach to include uncertain climate change information in decision-making. Case studies of this approach are currently under development and are available at <http://agwaguide.org/casestudies/>.

4.2.2 Case studies

Case study 28: France / Mapping the vulnerability of territories to climate change in the water sector in the Adour Garonne basin [58]

Models and scientific knowledge converge to predict that by 2050, climate change will generate major hydrological changes and will have significant repercussions on the water management and aquatic environments of the Adour-Garonne basin, including:

- A rise in sea levels
- An increase in annual temperature of about 2 °C.
- A decrease in annual rainfall of about 15% but an increase in extreme precipitation
- A rarefaction of snow in the mountains
- An increase in evapotranspiration of between + 10% and + 30%
- An average annual decline in discharge of between -20% and -40% with earlier, more severe and longer lower flow periods
- An increase in water temperatures
- Drier soils
- An increase in the risk of eutrophication,
- An evolution of both aquatic and terrestrial ecosystems involving a modification of vegetation, flora and fauna.

These impacts are already being felt today and are likely to cause a great deal of stress on low-water resources, a deterioration of water quality, a weakening of aquatic environments, and more frequent torrential floods. At the same time, the combination of global warming and demographic projections will increase the water needs of plants and human activities. The result may be limited

(Cont'd)

access to water for both drinking water and as an essential support for the economy (agricultural and industrial) in the basin. Everyone's access to water in quantity and quality is at stake.

In response to this challenge, in parallel with the SDAGE (designed to solve the current problems of water management), the Basin Committee of the Adour Garonne Basin Agency decided to initiate a plan for adapting to climate change in the field of water (PACC). The PACC anticipates these changes by imagining new measures to limit future water management problems. This plan is based on a study (mapping) of the territorial vulnerabilities to climate change in the water sector and ultimately proposes adaptation measures in the Adour Garonne basin and recommended actions at local level.

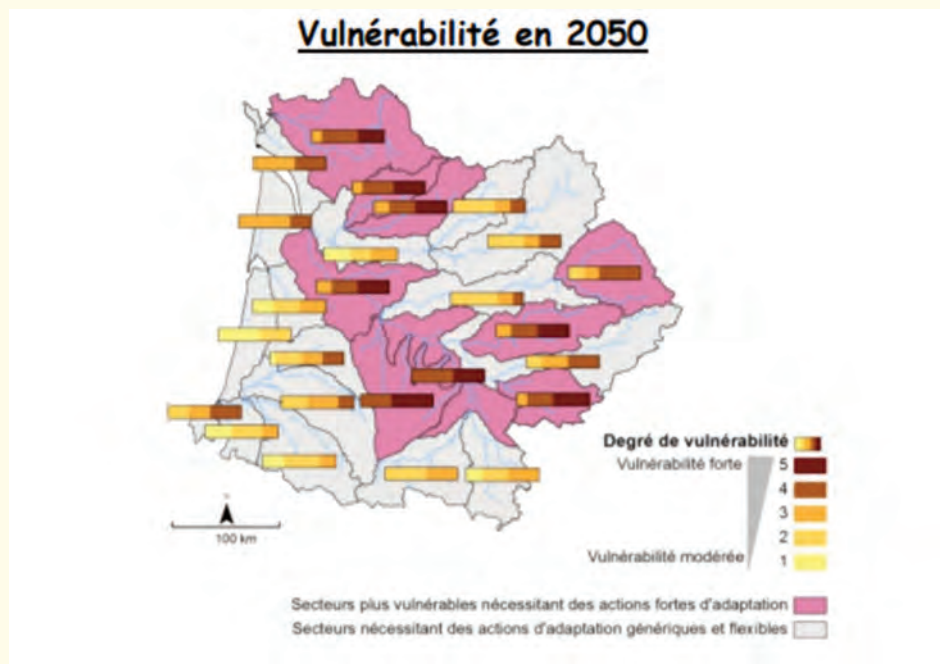


Figure 39: Example of a map showing the watershed's vulnerability to eutrophication

Case study 29: Climate Change Knowledge Portal (CCKP) [59]

In an effort to serve as a 'one stop shop' for climate-related information, data, and tools, the World Bank created the Climate Change Knowledge Portal (CCKP) (<http://sdwebx.worldbank.org/climateportal/index.cfm>), supported by the Global Facility for Disaster Reduction and Recovery and others. The portal provides an online tool for access to comprehensive global, regional, and country data related to climate change and development.

The portal is a web-based platform developed to assist in capacity building and knowledge development on climate and climate-related issues across the development community. Additionally, the portal was developed to help project teams to plan, monitor and evaluate project responses with respect to climate change risks.

Climate Change Knowledge Portal toolkit:**1. Rapid Risk Screening:**

- Multiple sources of information
- Historical variability
- Development and vulnerability information

2. Custom Analysis

- Downscaled data extracted by pre-defined or user-defined region
- Analysis routines

3. Downloads Site

- Download daily information by year or time period
- For use in impact models and other relevant applications



Figure 40: Example of visualisation on the Climate Change Knowledge Portal

The CCKP contains environmental, disaster risk, and socio-economic datasets, as well as synthesis products, such as the Climate Adaptation Country Profiles, which are built and packaged for specific user-focused functions such as climate change indices for a particular country. The portal also provides intelligent links to other resources and tools.

The CCKP consists of spatially referenced data visualized on a Google Maps interface. Users can evaluate climate-related vulnerabilities, risks, and actions for a particular location on the globe by interpreting climate and climate-related data at different levels of detail.

Examples include: World Bank and external datasets related to agriculture; water runoff projections; natural disasters; socioeconomic statistics; and low-carbon growth studies, among others. All of the datasets are presented in both a pixel and aggregated basis (country, regional, and watershed).

4.3 Early warning systems for flood and drought period management

KEY POINTS

- The human and economic impacts of flood and drought periods can be particularly high, and information systems on these aspects can help to mitigate the risk and to reduce these impacts;
- Information and adapted tools supporting risk knowledge, communicating warnings to reduce disaster risks, and considering environmental and social vulnerability assessment, are of crucial importance;
- Information systems in this domain generally take a multisectoral approach as they require combining data sources from national weather and hydrological services, agricultural extension services, and public databases, as well as data streams from international partners providing remote sensing datasets

4.3.1 Stakes and data/information needs for flood and drought period management

Improving drought and flood forecasting and early warning systems is essential considering the potential human and economic impacts of these events. As part of the measures to improve adaptation to climate change, early warning systems can also help decision-makers and private individuals to prepare for climate-related natural hazards and improve their readiness to harness favourable weather conditions.

Early warning systems for natural hazards need to have a sound scientific and technical basis, and focus on the people exposed to a particular risk. They should include a systems approach that incorporates all of the relevant factors in that risk, whether arising from natural hazards or social vulnerabilities, and from short - or long-term processes. An effective, comprehensive early warning system comprises four interacting elements, namely:

- Risk knowledge,
- Monitoring and warning service,
- Dissemination and communication,
- Response capability.

Early warning systems are usually cost-effective non-structural measures. Their cost is non-negligible in absolute terms and extremely low in comparison with the potential losses that these systems can reduce. [60] [61]

Flood risk warning systems [62]

Floods have the potential to cause fatalities, displace people and damage the environment; they can severely compromise economic development and undermine the economic activities of a community. [63]

Throughout the world, different types of floods occur, such as river floods, flash floods, urban floods and floods from the sea in coastal areas. The damage caused by flood events may also vary across countries and regions.

Information systems included in flood warning systems should facilitate data access, processing and management, as well as the dissemination of information necessary for:

- Forecasts of hydro-meteorological phenomena that could cause floods, coupled with early warning systems;
- Protection against floods (dikes, diversions, retarding reservoir dams, dynamic braking, storage areas, catchment area management);
- Prevention that involves the mapping of hazard-prone areas, according to different levels of hazard (decadal, centennial floods, and even beyond) and an estimate of vulnerability.

A flood warning system relies on an effective service, which is forecasting floods on the transboundary basin scale, and operates closely with member states and specialized national agencies (meteorological and hydrological services). The central warning service could be installed in the transboundary basin organization, if its mandate includes flood control.

Once fed with meteorological and hydrological data, the service is able to calculate the evolution of run-off in the basin and consequently of water levels in streams and rivers. This is then compared with predefined warning levels to provide information on the occurrence of risk or not, and determine the onset of the alert. The signals related to flood forecasting should be addressed to governments that are responsible for protecting people and property and for implementing adequate and graded procedures.

In addition, in order to establish an effective information tool and a valuable basis for priority setting and further technical, financial and political decisions regarding flood risk management, it is necessary to establish flood hazard maps and flood risk maps. These maps show the potential adverse consequences associated with different flood scenarios, including information on potential sources of environmental pollution as a consequence of floods.

Drought early warning system

As part of drought early warning systems, information systems are designed to facilitate the identification of climate and water supply trends and thus to detect the emergence or probability of occurrence and the likely severity of drought. This information can reduce impacts if delivered to decision-makers in a timely and appropriate format and if mitigation measures and preparedness plans are in place. Understanding the underlying causes of vulnerability is also an essential component of drought management, considering that the ultimate goal is to reduce risk for a particular location and for a specific group of people or economic sector.

At present, the analysis and preparation of information are particularly critical parts of an early warning chain. Decision-makers are usually confronted with huge amounts of structured and unstructured data. To enable reliable early warning, the available data must be pre-selected, analysed and prepared. The decision-makers should be provided with a reliable and manageable amount of information to make the warning decision and take preventive measures. Limitations include failure to allow for non-climatic confounding factors, limited geographical/temporal resolution, and lack of evaluation of predictive validity.

The need for interinstitutional cooperation

In many countries, data needed for implementation of drought monitoring systems are scattered around multiple agencies that are dependent on different ministries. This requires collaboration across ministries through a multi-sectorial approach, which often cannot be effectively implemented without direct support from high-level policy makers. Monitoring and early warning systems require combining data sources from national weather and hydrological services, agricultural extension services and public databases as well as data streams from international partners providing remote sensing datasets to fill data gaps, particularly in Africa, or global/regional weather and climate model outputs. This requires technological solutions that allow the integration of multiple data sources with different temporal and spatial resolutions. An additional challenge is that they often have a complex data structure with data exchange formats that need to be handled to allow their integration in a seamlessly working system.

4.3.2 Case studies

Case study 30: Drought and flood monitoring system in Africa and Latin America [9]

UNESCO-IHP supported the development of an integrated flood and drought monitoring and forecasting system for Africa and Latin America [64]. The system (<http://stream.princeton.edu/>) developed by the University of Princeton in the United States combines remote-sensing data on precipitation, vegetation and atmospheric analysis with macro-hydrological modelling through the use of a Variable Infiltration Capacity (VIC) land-surface hydrological model [65]. The system tracks hydrological conditions including extremes (e.g. floods and droughts) in near real time and allows medium-term and seasonal forecasting. It therefore provides monitoring capabilities for meteorological, hydrological and agricultural drought and flood conditions, which is particularly useful in developing regions where institutional capacity for monitoring and early warning is generally lacking and access to information and technology prevents the development of such systems locally. In addition, the system has the advantage of providing a standardized format for any of the components of the water balance, thus enabling a comprehensive analysis of drought and flood hazards at local, national and regional level. In essence, the system provides information on precipitation, temperature, radiation and wind speed, drought indicators (i.e. Standardized Precipitation Index - SPI, soil moisture, Normalized Difference Vegetation Index - NDVI, evapotranspiration) and flood indicators (i.e. surface runoff and streamflow). The information can be obtained either spatially or for point locations, for specific dates, months or annual timescales, and is compared with the normally expected conditions or percentiles. The system has been successfully deployed in Western, Eastern and Southern Africa combined with training of experts and is used as a complementary information system by regional institutions to monitor agro-hydro-meteorological conditions particularly during the rainy season.



Figure 41: Interface of the Latin American Flood and Drought Monitor

Case study 31: The Hydrological Status and Outlook System HydroSOS [21]

WMO HydroSOS strives to build an operational system capable of assessing the current status of surface and groundwater hydrological systems, and predicting how they will change in the coming weeks and months, in comparison to normal situations. This information can be critical for water management and mitigating negative effects of floods and droughts, as well as to reduce risks of conflicts in water sharing. Once operational, the worldwide operational system will regularly provide information on:

- ❶ Current global hydrological status, including groundwater, river flow, large lakes, reservoirs and soil moisture;
- ❷ Appraisal of where the current status is significantly different from 'normal', for example indicating potential drought and flood situations; and
- ❸ Assessment of trends i.e. likelihood of improvement or worsening over coming weeks and months.

HydroSOS will be built on the following components:

- In situ data: river flow, soil moisture, large lake and reservoir levels and groundwater depths;
- Global/regional-scale remotely sensed satellite data: precipitation, soil moisture, aquifers, and snow cover/depth;
- Global/regional weather and climate forecast models: precipitation and temperature; and
- Global/regional/basin scale hydrological models: river flow, soil moisture, groundwater

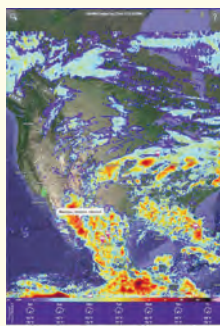
The WMO HydroSOS will directly build on existing and planned WMO initiatives in relation to hydrological monitoring, data sharing and sub-seasonal to seasonal meteorological forecasting, to deliver a unique operational system providing up-to-date hydrological information and products from National Meteorological and Hydrological Services to a wide range of end-users. The operational system will support their activities and provide easily accessible hydrological information and products that can be made accessible to government bodies as well as to regional and international aid agencies and the general public.

Case study 32: Precipitation Estimation from Remotely Sensed Information (PERSIANN-CCS) [9]

UNESCO-IHP has collaborated with the Center for Hydrometeorology and Remote Sensing (CHRS) at the University of California, Irvine, on the development of tools to provide near real-time global satellite precipitation estimates at high spatial and temporal resolutions, including the Precipitation Estimation from Remotely Sensed Information using the Artificial Neural Networks-Cloud Classification System (PERSIANN-CCS) [66]. This specific system is used to inform emergency planning and manage hydrological risks, such as floods, droughts, and extreme weather events. For example, the Namibia Drought Hydrological Services (NHS) uses it to prepare daily bulletins with up-to-date information on flood and drought conditions for local communities.

The system is now available through the iRain mobile application, devoted to facilitate people's involvement in collecting local data for global precipitation monitoring

(<http://en.unesco.org/news/irain-new-mobile-app-promote-citizen-science-and-support-water-management>). iRain allows users to visualize real-time global satellite precipitation observations,



track extreme precipitation events worldwide, and report local rainfall information using a crowd-sourcing functionality to supplement the data, which provides opportunities to improve remote-sensing precipitation estimations.

Figure 42: The iRain Mobile Application

Case study 33: Drought indicators in Chile [9]

In close collaboration with the Chilean Ministry of Agriculture, the Food and Agriculture Organization (FAO) and the International Research Institute for Climate and Society (IRI), the Chilean Agroclimatic Observatory (www.climatedatalibrary.cl/UNEAMaproom/) was launched in June 2013. A similar system was developed in collaboration with the Autoridad Nacional del Agua (ANA) in Peru in 2014 (<http://ons.snirh.gob.pe/Peru/maproom/>). The system is used to create integrated indices, taking into account a number of different drought indicators. The system builds upon the Climate Data Library (CDL), a tool that collects all raw databases relevant to drought monitoring from national and international institutions [67]. Data in numerous formats can be added, and additional indicators can be calculated using advanced arithmetic or geo-statistical functions. In order to provide effective decision-support tools, a user-friendly interface was built on top of the CDL, called the “maproom”, which holds relevant drought indices on meteorological, hydrological and agricultural drought, and combines information from national and international datasets.

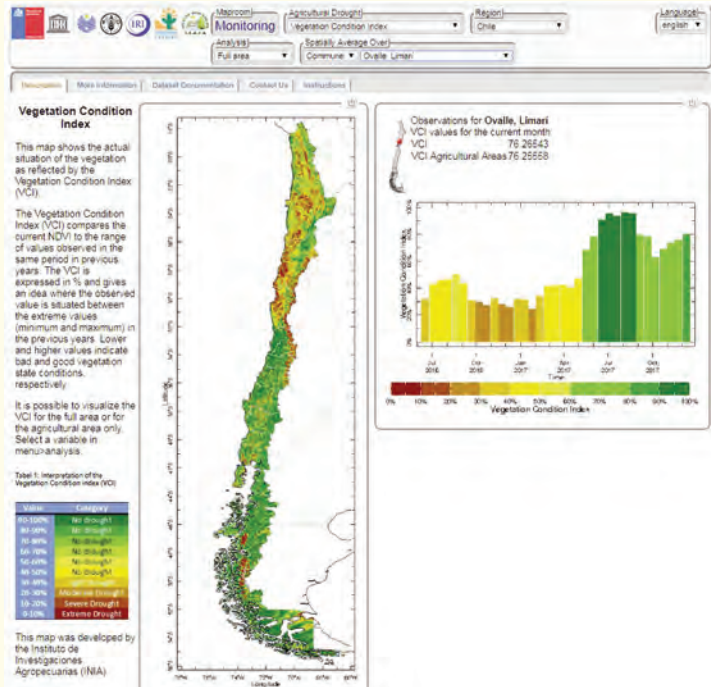


Figure 43: Information on drought available on the Chilean Agroclimatic Observatory

Case study 34: Flood and Drought Management Tools [68]

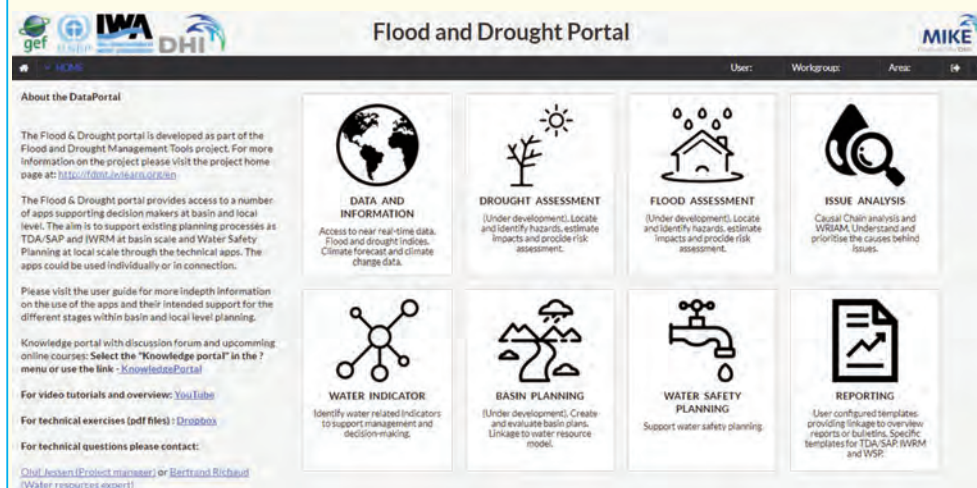


Figure 44: IWA Flood and Drought Portal home page

Climate change is increasing the occurrence of severe and unpredictable flood and drought events. These events together with fast growing populations, urbanization, land use and water demand are putting pressure on water resources and increasing the risk for many countries, affecting river basin organizations and other end-users such as utilities and industries. In transboundary basins, these risks are larger because of the challenge of multiple countries competing for the same water resources.

To reduce water related risks, land, water and urban managers need to improve their ability to recognize and address flood and droughts risks and improve resilience. Cooperation across borders and scales is fundamental, as is the integration of information on flooding and drought in planning processes, such as Transboundary Diagnosis Analysis/Strategic Action Programmes (TDA/SAP) and Integrated Water Resources Management (IWRM) at basin level and Water Safety Plans (WSP) at local (water utility) level.

The Flood and Drought Management Tools (FDMT) (www.flooddroughtmonitor.com) project is funded in 2014 by the Global Environmental Facility (GEF), International Waters (IW) and implemented by the United Nations Environment Programme (UNEP) with DHI and the International Water Association (IWA) as executing agencies. This project is developing a package of web-based technical applications (tools), accessible through the Flood and Drought Portal (www.flooddroughtmonitor.com).

Case study 35: DRIDANUBE - AN INNOVATIVE TOOL FOR DROUGHT MANAGEMENT [69]

In the framework of ICPDR activities, the DriDanube project is developing an innovative and interactive tool, the Drought User Service (DUS), which will enable more accurate and efficient drought monitoring and early warning for the entire Danube region. It will include a set of Earth Observation data from a range of operational remote sensing satellites, which are processed into ready-to-use drought information, available to the general public with a web-browser interface. With this service, the operational day-to-day work of national authorities, and end users such as farmers and water managers, will be improved in all phases of drought-related disaster management (from monitoring, forecasting and evaluation to response).

The available data product catalogue will provide several products generated from satellite data, e.g. surface soil moisture, vegetation status, and maps with a forecast of the expected agricultural yield. The products will be pre-processed by the DriDanube project partners and provided on a daily to weekly basis in order to map dynamic drought events. The inspection of the products will be done via an easy-to-use web-interface (see Figure 2). Furthermore, the interface can be used to overlay auxiliary map layers like OpenStreetMap and administrative boundaries.

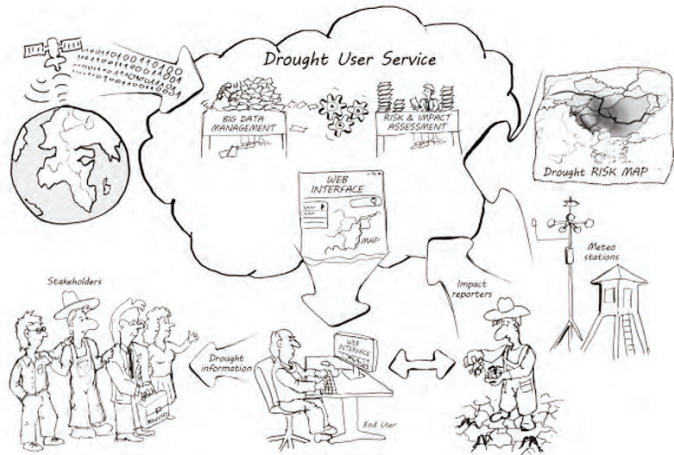


Figure 45: Simplified Drought User Service scheme

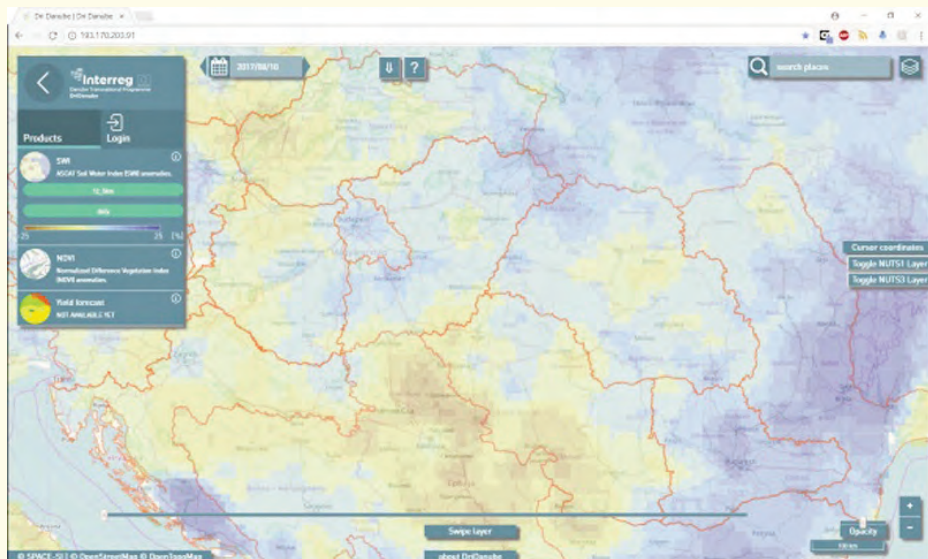


Figure 46: Prototype of the Drought User Service (DUS) interface

4.4 Water information systems for aquatic ecosystem protection

KEY POINTS

- Aquatic ecosystems provide several services for producing, regulating and structuring on different time and spatial scales;
- Organizing the access and processing of datasets improves our understanding of how ecosystems provide services and how changes to ecosystems impact service provision.

4.4.1 Stakes and data/information needs for ecosystem protection

As a subset of ecosystems, inland surface aquatic ecosystems related to rivers, lakes and wetlands are a key component of integrated water resources management.

A wide variety of aquatic ecosystems exist, and although they represent a low percentage of the Earth's surface, their roles and functions make them crucial. An aquatic ecosystem in good condition can carry out diverse functions that can be grouped into several families:

- Production functions, which mostly concern the production of organic matter, the availability of non-renewable resources like water, and mineral substances;
- Regulation functions – the way ecosystems function contributes to stabilizing the variability of natural processes (climate, natural risks, etc.) and resource flows (soil water retention). They also play a role in eliminating the transformation of toxins (water self-purification);
- Organization (or structuring) functions - these contribute to defining the system's self-organization rules. They involve the physical organization of systems (landscape structuring) and their biological organization (biodiversity)

Ecosystem services can be considered on different time and spatial scales, and can be apprehended at different levels, from local level (protection against natural risks, water sanitation, cultural functions) and national level (a country's water resources, national basins) to international level (transboundary basins, world water cycle, fight against climate change, etc.). They also vary over time: the water cycle takes place over the whole biosphere. Current datasets provide a reliable tool for understanding how ecosystems provide services and how changes to ecosystems impact service provision.

Describing the status and diversity of aquatic ecosystems is based on structuring parameters that determine their functioning characteristics.

From remote sensing to crowdsourcing, and including data produced by many national and basin organizations, the data sources for this characterization are multiple.

As ecosystems are heterogeneous and the provision of ecosystem services varies across space and time, geographic information systems (GIS) provide a powerful tool for visualizing and analysing the provision of ecosystem services within a landscape.

The proliferation of freely available satellite imagery and associated databases allows for a GIS-analysis of ecosystem services in areas of the world where few other forms of data are available.

4.4.2 Case studies

Case study 36: Satellite-based Wetland Observation Service – SWOS [15]

The Satellite-based Wetland Observation Service (SWOS) uses Earth Observation data (including data from ESA's Sentinel satellites) to generate mapping products and indicators of wetlands. Timely observations allow for dynamic monitoring of wetland conditions and changes (and their drivers) on a large spatial and temporal scale.

The service was initiated through a project funded by the European Commission's Horizon 2020 scheme, in which research bodies, user organizations and private companies embarked on an ambitious path to create an open-access tool to monitor wetlands. The outcomes generated are demonstrated for a range of selected wetlands in Europe, Africa and Asia to ensure the methodology is applicable globally.

SWOS assists wetland practitioners (managers, policy-makers, scientists) with wetland monitoring and with reporting obligations for environmental policy implementation at different scales (including SDG6).

SWOS provides a toolbox for users experienced with satellite data to process these data and generate map products (e.g. inventory and delineation, land use land cover and short- and long-term changes, surface water dynamics, soil moisture, water quality, surface temperature) and indicators. Non-expert users can directly access final products online from the SWOS portal, which also provides access to raw satellite data and external data resources. All map products are provided with Inspire-compliant metadata for easier integration into global wetland portals such as GEO-wetland.

Geoclassifier is available as standalone software, but also as a plug-in for Arc-GIS and soon for QGIS

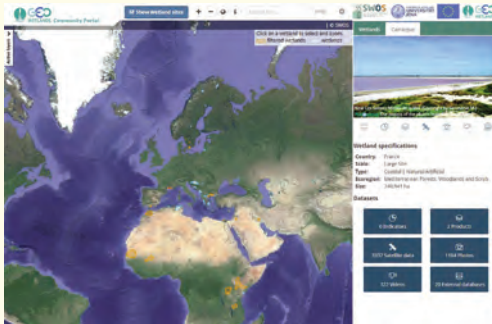


Figure 47: SWOS data portal

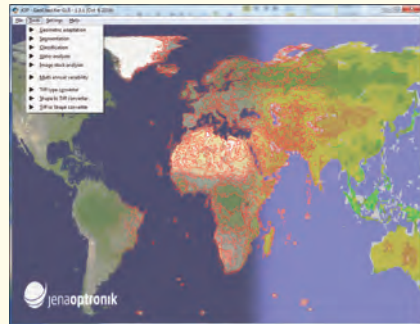


Figure 48: Geoclassifier toolbox

Case study 37: BaladOmarais mobile application [17]

BaladOmarais is a mobile application developed by IOWater that can be used for discovering wetlands in mainland France, French overseas territories and French-speaking countries, by



geolocation or in your area. It can be used to find the coordinates of wetland information centers. As an example, each year, the app inventories events organized around World Wetlands Day (2 February).

Figure 49: BaladOmarais mobile application

4.5 Sectorial and thematic water information systems (drinking water and sanitation, irrigation, hydroelectricity, groundwater, etc.)

KEY POINTS

- In many countries, water-related information systems are organized per topic and per sector of activity: these systems are often managed by the national organization in charge of the domain;
- Each of these thematic/sectorial water information systems includes specific functionalities adapted to the needs of the domain concerned

4.5.1 Stakes and data/information needs for thematic and sectorial WIS

In many countries, institutions are developing specific thematic and sectorial water information systems, e.g. to manage their:

- Meteorological data
- Hydrological data
- Surface water quality data
- Ground water data
- Data on protected area
- Data on water uses
- Data related to water intake area
- Irrigation sector
- Water supply and sanitation
- Energy sector

They are generally managed by the organization in charge of the domain in the country.

These systems make it easier to discover, collect, access, manage and/or make best use of existing datasets, and are also used for communication on the domain.

In addition, specific functionalities of these water information systems are related to the main management challenges in each domain.

The main issues related to the irrigation, drinking water, and sanitation sectors are set out below.

About the information system used in the irrigation sector

In the area of irrigation, a WIS is mainly employed to assess water requirements at the beginning of the season (planning) and to allow managers to plan and manage the distribution of resources, which in the case of cross-border management may be subject to treaties and hence results obligations with far wider consequences than the agricultural sector.

Data relating to crop water requirements are preferentially coupled to GIS tools for more precision, while infrastructure data (canals, dams, etc.) are generally associated with what is known as the "water cadastre", which in many countries is an integral part of the WIS.

The monitoring of the volumes collected and distributed is done according to the scale and type of system (gravity or under pressure) by means of counters or remote control / SCADA-type telemanagement, which can treat in real time a large number of telemetry and remotely control technical installations (e.g. valve openings).

In gravity systems, flow control is of particular importance in terms of the efficiency of the operation and maintenance of the structures. Various management software programs have

been developed by irrigation operators, including the well-known "dynamic regulation".

On site, irrigation management software monitors as closely as possible the water needs of plants considering weather conditions.

The main difficulty of WIS in agriculture is the interoperability of the tools put in place at different levels (GIS, DB, reporting systems, etc.), the continuity of the transmission circuits, and the quality control of the transmitted data. Basic data, particularly on irrigated areas, are often outdated and the exchange of information is mainly manual, giving the systems a high degree of inertia and relative reliability.

Strengthening the management of data and information on agricultural water is essential to improve the planning, distribution and rational use of all water resources, in terms of irrigated perimeters but also by the allocation rules they induce at sub-basin level

About the WIS used in the drinking water sector

WIS are increasingly important in the management of water and sanitation services. They are found in many service activities, the main ones being:

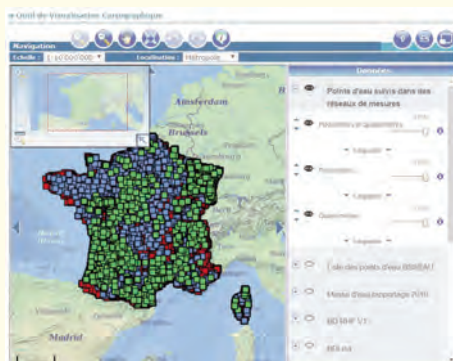
- Patrimonial management, for which a GIS system is generally in place. It can produce a mapping of the networks, which can then be associated with data, such as the nature of the materials and the age and diameter of the pipes. The GIS also features all of the works and equipment that make up the drinking water system or sanitation system;
- Commercial management that uses dedicated CRM-type software. This is used to manage the customer database as well as all commercial activities: billing, complaints management, communication with subscribers, monitoring the meter park, meter reading, etc.
- Financial management that also uses dedicated software;
- Maintenance management using CMMS (computerized maintenance management systems) type software;
- The operation of works that generally use a remote monitoring system to ensure their proper functioning. The information collected automatically on each site is transmitted to a centralized station that allows live visualization of the operating status of facilities and can potentially manage actions remotely.

The development of WIS plays a central role in improving the performance of water and sanitation services (cf. case study on SISPEA). The management of all data generated by surveillance equipment is a crucial issue and a subject on which progress is expected in the coming years.

4.5.2 Case studies

Case study 38: ADES - French National Data Base on Groundwater [70]

The ADES website (<http://www.ades.eaufrance.fr>), managed by the BRGM with the financial support of AFB, provides public access to



data on groundwater chemical quality and groundwater levels, the mapped results, metadata, and a series of information updates. As a one-stop point of access to relevant information, it constitutes an essential tool for optimal management of water resources, enhances understanding of groundwater changes, and contributes solutions for local, national, societal and European issues.

Figure 50: Example of ADES web pages

*(Cont'd)***Discovering groundwater monitoring networks**

Data come from more than 70,000 representative monitoring stations scattered all over the country. These stations measure key components of groundwater quality (qualitometers), and groundwater levels (piezometers). Some stations can insure both measurements. The ADES data bank gives access to descriptive data sheets for all of the monitoring stations: geographical coordinates, location on a map, station operators (water agencies, local and regional authorities, decentralized state administrative authorities, the French geological survey –BRGM, etc.), measurement frequencies, aquifers monitored, etc.

#Carrying out an effective search

The ADES data bank proposes several ways to access observation stations, technical data sheets, and data on quality (chemical analyses results) and/or groundwater levels (piezometric head). It features numbered buttons for quick access.

- Quick access, by entering free expression in empty boxes with localization, type of data you are looking for (monitoring station, parameter, water level);
- Advanced search page: you can select by location on a map, or by specific network, company, aquifer, groundwater body or national code (BSS1).

Whatever the access route, the results can be stored for later use.

Access, view, data export

The ADES website provides access to export sets of data and offers users various features such as:

- Maps and photos;
- Graphs: plot two chemical parameters for the same qualitometer on the same chart, and up to five for a piezometric station.
- Reliable indicators that are up-to-date, comparable and meet the needs of end-users.

The website also offers an indicator on the hydrogeological situation of a piezometer for a long period (minimum 10 years), with tables, graphs and maps.

Case study 39: SDC project/ Water Accountability in Transboundary Chu-Talas River Basins [17]

The project “Water Accountability in Transboundary Chu-Talas River Basins” financed by SDC, aims to promote modern, sustainable and transparent water resources management in the Chu-Talas River Basins that can serve as a blueprint for effective transboundary resources management at national and regional level.

This project focuses on the complete modernization of bottom-up demand scheduling and a top-down supply-driven water distribution system in the Chu-Talas River Basins. It includes:

- Full digitization and automation of the accounting procedures in place with state-of-the-art information technology;
- Development of new capabilities for planning, effective operational analysis, as well as reporting and data/knowledge exchange.

Whereas in the existing system, data requests had in many cases to be laboriously communicated via fax and/or telephone, thanks to a modern digital WIS-type system, stakeholders will be able to immediately query selected data on their computer terminals and/or tablets safely and securely.

The data will be available for operational use and / or for reporting etc. and prepared in a way that it is easily accessible and understandable for all stakeholders, from the WUA level up to the national and transboundary scales.

The activities led by IOWater in collaboration with hydrosolutions Ltd. and local expert consultants, mainly aim to increase water delivery effectiveness through better on-time data management, processing, and information production and dissemination. Among the main results it is particularly expected that thanks to the improvement of the water data management procedures:

- At local level, the authority in charge of water allocation for irrigation will have the capacity to follow online (on a tablet) the status of water allocation on a daily basis;

(Cont'd)

- At basin and national level, the national and basin authority will have access to new national information services (reports, indicators, bulletins, maps) facilitating the analysis of water allocation efficiency per sector and per canal;
- At transboundary level, transboundary data sharing will be reinforced with regular production of transboundary bulletins on the water resource and water allocation situation.

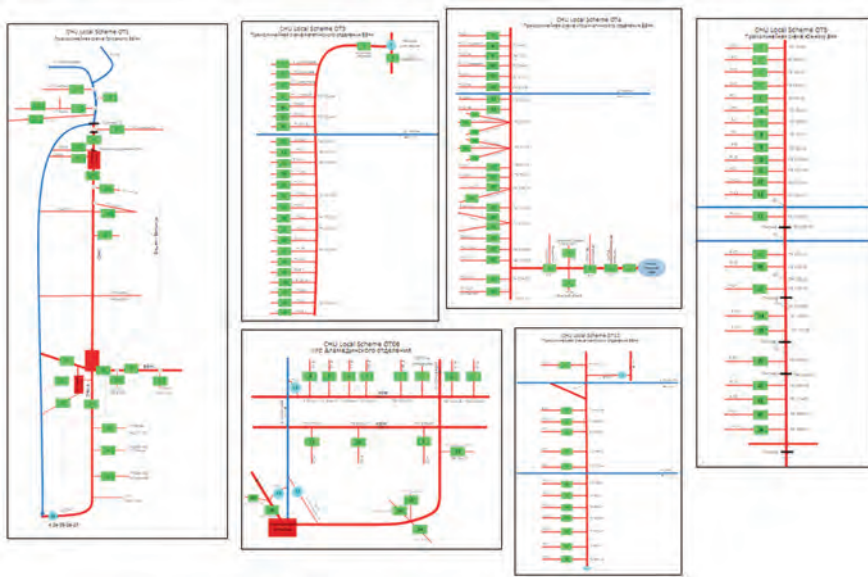


Figure 51: Example of interactive irrigation schemes on the Chu basin in Kirghizstan

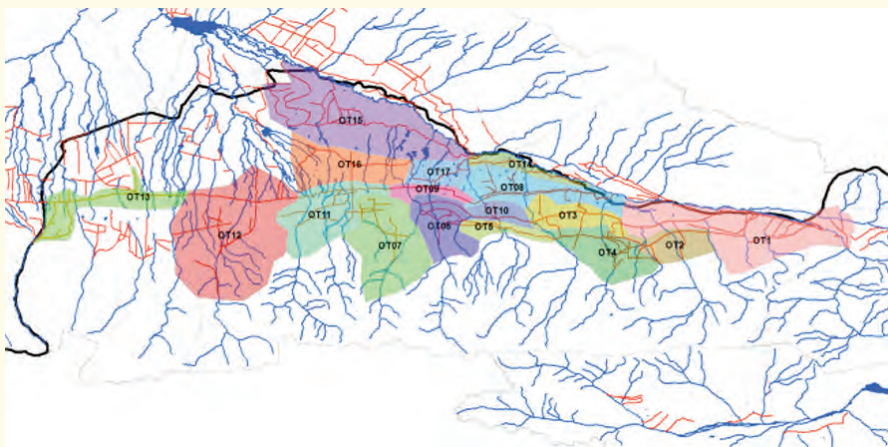


Figure 52: Draft georeferenced delineation of irrigation unit on the Chu basin in Kirghizstan

Case study 40: Aires - Areas of protection of drinking water catchments [14]

The setting up of a resource centre by the French Agency for Biodiversity (AFB) aims to improve the effectiveness of a local approach to the protection of water catchment areas.

As part of this resource centre, the International Office for Water (OIEau) is creating a web portal intended for stakeholders involved in all the catchment areas involved. This portal (<https://aires-captages.fr/>) encourages stakeholder networking, centralizes and disseminates some resources (data, documentation) on catchment protection, and combats diffuse pollution: all scientific and technical resources (tools and methodology) are available for final users.

Each section of the portal is designed to respond to the needs of the facilitators of all of the catchment areas. The creation of a specific fact sheet describing each catchment area in France is an innovative approach. The information contained in these sheets comes from external databases but also from data directly entered by some of the portal's users. This web portal is linked to other websites in order to make the selection of useful documentation easier and indicate training sessions for stakeholders involved in all catchment areas. Finally, the portal disseminates the work carried out by the resource centre and by numerous partners of this project. OIEau conducted a survey of European countries to identify their practices against diffuse pollution. OIEau showcases these European member state experiences on the web portal.

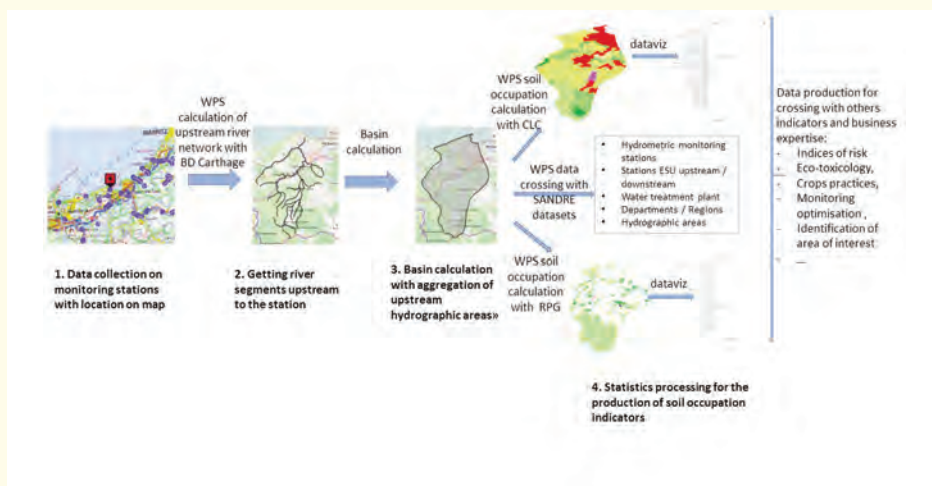


Figure 53: Example of data processing with the application Aires

Case study 41: GisAgua - Aguas de La Habana [71]

GisAgua is a GIS application specialized in the integrated management of the urban water cycle by means of the administration of a geographically referenced database that groups information on cartography, supply and sewerage. The development of GIS facilitates the consulting and spatial assessment of the infrastructure's data, speeds up decision-making and provides aqueduct companies with a modern tool for to plan, operate and maintain their system.

The development offers all the editing, analysis and results presentation that characterize GIS. Within its potentials, one can find the customized tools for the work on the aqueduct infrastructure (Figure 1), with the purpose of demarcating failures or scheduled shut downs, areas affected by the lack of water, connections to the network's mathematical models, studies of water losses, direct ties with the users and follow-ups during the maintenance periods. Likewise, it has specific developments for the management and assessment of the sewerage network, as well as for the elaboration of new supply, sewerage, and rainwater drainage projects.

The use of geographical locations is an important function used by the system to define exploitation parameters. The multi-user editing on the Data Base makes the system provide fast instruments for constant update. GisAgua can be the entrance and exit point for an important number of computer applications of general use in a water supply company.

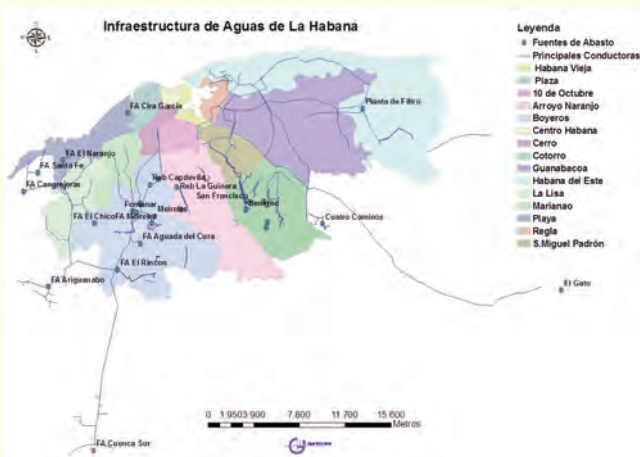


Figure 54: Some infrastructures of the “La Habana” main water supply network

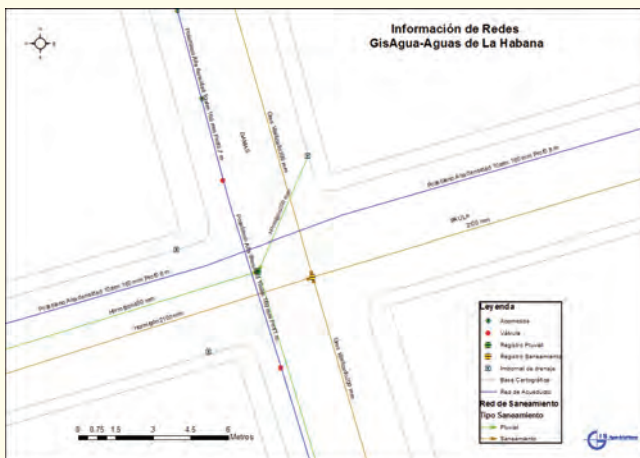


Figure 55: Example of information on the pipes of La Habana water supply network

The project GisAgua-Aguas de La Habana has become an essential tool for the development of the hydraulic and sewerage infrastructure of the capital city. It is considered to be of a great use for the planning and strategies in a short, medium, and long-term, due to its ability to generate multi-criteria studies with geographically referenced components. It has become a connection interface with entrance and exit points for the company's diverse control, management and operation computer systems. The tool goes beyond the borders of Aguas de La Habana by becoming an essential information source for urban growth and territorial organization projects, and studies on rational and productive use of water. The aforementioned project has laid the foundations for the development of water and sewerage information systems in Cuba by establishing the needs for its efficient development.

Case study 42: SISPEA - Water and Sanitation Public Utility Information System [72]

In France, as in a number of European countries, performance indicators (PIs) for monitoring water and sanitation utilities have been significantly developed. The challenge is to disseminate this information on the performance of utilities, to make it as accessible as possible and make relevant comparisons. ONEMA



with creating a monitoring system compiling both descriptive data and indicators of the French services, known as **SISPEA** (<http://www.services.eaufrance.fr/>), for **Water and Sanitation Public Utility Information System**. SISPEA officially started in 2009 (collection of data concerning the year 2008). Its role is to gather all data and performance indicators from local authorities or from their operators, to compare them and point out areas for improvement. It then produces an annual consolidated national report on the performance of water and sanitation services.

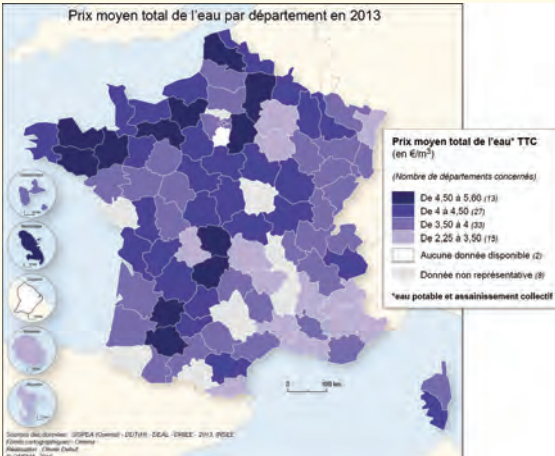


Figure 56: water prices in France per Department

Smartphone application

The Sispea smartphone application and the mobile site provide access to data on public water and sanitation services: management mode, price of services, yield, water quality, claim rate, etc., by geolocation or by search for a municipality.

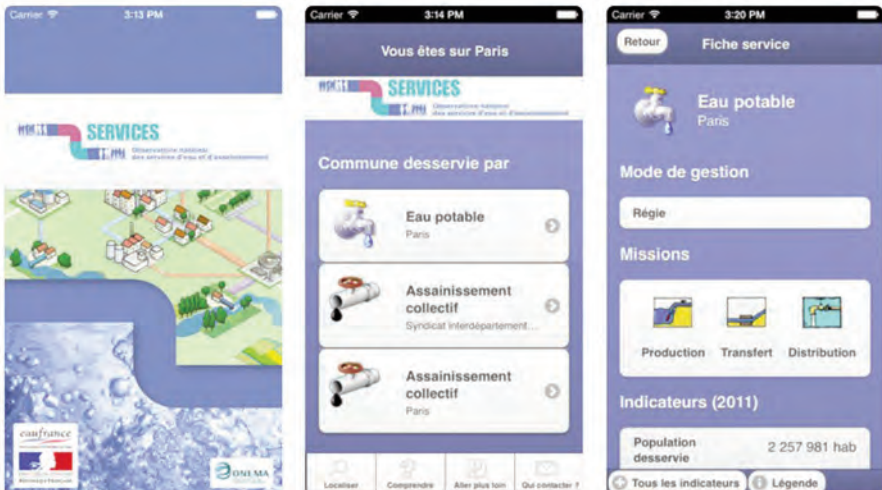


Figure 57: Interface of the Sispea smartphone application

4.6 Water information systems for reporting (SDG, WFD, Flood Directive, etc.)

KEY POINTS

- The adoption of global or regional programmes in the water sector such as the one related to SDG6 or the WFD requires periodic data reporting.
- Information systems linked to national water and or sectorial information are used for preparing and communicating the required indicators.

4.6.1 Stakes and data/information needs for reporting

The implementation of global or regional programmes or policies generally requires periodic data reporting by different stakeholders on status, progress and/or measures implemented at their level.

This is particularly the case in the water sector for:

- SDG6, dedicated to water and sanitation within the framework of Agenda 2030;
- The European Water Framework Directive and its daughter directives (Flood risks, bathing water, urban waste water, etc.);
- etc.

Specific information systems are often used for preparing and communicating the required indicators. The related tools for data access, indicator processing and diffusion are more efficient when linked to national water and sectorial information. They are sometimes integrated into national water information systems.

Case of SDG6 reporting

The international community as a whole, regional institutions, and groups of states have established over the years a number of mechanisms at regional and global level for the collection of water-related data and information for purposes ranging from supporting navigation, to monitoring and preventing pollution, protecting the environment and supporting sustainable development. The required parameters to be measured and the frequency of the reporting vary widely according to the intended purpose of the process.

Of particular relevance in this context is the adoption by the UN general Assembly of the Agenda 2030 and the related Sustainable Development Goals, especially SDG-6 on water and sanitation and its related targets:

- Achieve universal and equitable access to safe and affordable drinking
- Achieve access to adequate and equitable sanitation and hygiene for all
- Reduce the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
- Increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply
- Implement integrated water resources management
- Protect and restore water-related ecosystems,
- Expand international cooperation and capacity-building support

To meet the monitoring and information needs of the 2030 Agenda, the Integrated Monitoring Initiative for SDG 6 has been launched by UN Water, building on and expanding the experience and lessons learned during the MDG monitoring and reporting period. All of the custodian agencies of the SDG 6 global indicators have come together under the Initiative, which also includes the work of WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP), the inter-agency GEMI and UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS).

The objectives of the Integrated Monitoring Initiative are to:

- Develop methodologies and tools to monitor SDG 6 global indicators
- Raise awareness at national and global levels about SDG 6 monitoring
- Enhance technical and institutional country capacity for monitoring
- Compile country data and report on global progress towards SDG 6

Illustrating the importance of monitoring progress towards the Sustainable Development Goals (SDGs), the UN Deputy Secretary-General Jan Eliasson said that data are the “lifeblood of decision-making and the raw material for accountability”,

Box 19: About IHP WINS for monitoring the progress made toward SDF6 [9]

IHP-WINS (presented in detail in case study n°17) was launched by UNESCO-IHP in January 2017 as a tool to foster and support the monitoring of progress made towards SDG 6. IHP-WINS builds on Resolution XXII-7 of UNESCO-IHP's 22nd Council session, held in June 2016, which requested the UNESCO-IHP Secretariat to “*provide support to Member States to build their institutional, human and communities' capacities and a sound basis in science capacity for the monitoring and implementation of Sustainable Development Goal 6 (SDG 6) targets and those of other water related goals*”.

In the framework of the 2030 Agenda for sustainable development, UNESCO is co-custodian of SDG Indicator 6.5.2 on transboundary water cooperation. In this regard, IHP-WINS will allow UNESCO-IHP to provide all of the results on the progress made towards this Indicator 6.5.2.

As such, IHP-WINS platform is a key tool in the implementation and monitoring

Case of WFD reporting [73]

The WFD incorporated into a legally binding instrument the key principles of integrated river basin management:

- A participatory approach in planning and management at river basin scale;
- Consideration of the whole hydrological cycle and all pressures and impacts affecting it;
- Integration of economic and ecological perspectives into water management.

It also introduced a number of key principles into the management and protection of aquatic resources:

- An integrated planning process at the scale of river basins, from characterization to the definition of measures, to reach environmental objectives;
- A comprehensive assessment of pressures and impacts on, and status of, the aquatic environment, including from an ecological perspective;
- An economic analysis of the measures proposed or taken, and the use of economic instruments;
- An integrated water resources management principle that encompasses both environmental objectives and objectives of water management and related policies;
- Public participation and active involvement in water management.

In relation with the WFD, WISE is used as a depository and various tools are made available to facilitate reporting. However, countries have to prepare datasets for this reporting using common data dictionaries and tools.

Article 18 of the WFD requires the European Commission to publish assessment reports on the implementation of the Directive and to submit them to the European Parliament and to the Council. **The assessment is based on information reported by Member States**, comprising published RBMPs and accompanying documentation required according to Article 15, **electronic reporting through the Water Information System for Europe (WISE) in predefined formats agreed by the Water Directors**, and any additional, supporting background documents that the Member States consider relevant.

4.6.2 Case studies

Case study 43: WISE - Water Information System for Europe [74] [75] [76]

The result of a joint project involving the European Commission/DG Environment, Eurostat, the Joint Research Centre and the European Environment Agency, the Water Information System for Europe (WISE) (<http://water.europa.eu/>) is a shared information system providing water-related information available at European level. It works to modernize and streamline the collection and dissipation of information related to European water policy. Its formal reporting framework is the European Water Framework Directive.

WISE was launched for public use as a web-based service in 2007 providing a web-portal entry to water-related information ranging from inland waters to marine waters. The web-portal is grouped into sections covering:

- EU water policies (directives, implementation reports and supporting activities, etc.);
- **Data and topics** (reported datasets, interactive maps, statistics, indicators);
- **Modelling** (current - and forecasting services across Europe);
- **Projects and research** (inventory for links to recently completed and ongoing water-related projects and research activities).

The main objectives of WISE are:

- To provide a single entry point to access harmonized, high-quality European water data and information provided by mainly Member States;
- To assess and compare environmental status and trends related to water and their associated pressures and impacts from human activities including the underlying socio-economic driving forces;
- To check the compliance with and implementation of European water legislation and national laws and inform the citizens thereof;
- To use the collected information to assess the effects and effectiveness of EU water policy.



Figure 58: Example of WISE application interface

The system in particular offers the public access to water data and information reported by Member States to the EEA and the European Commission under the Water Framework Directive. The WISE-WFD database contains data from River Basin Management Plans reported by EU Members. The full database is not yet available for public download. However, a number of aggregation queries have been made: these queries extract data from the database and present it as data tables that can be downloaded in Excel format. WISE demonstrates how multi-national information on the environment can be streamlined, harmonized, quality assessed and made public for mutual benefit using state-of-the-art information technology.

Case study 44: Project “UWWT SIIF”: a free tool for European countries to speed up the availability of national sanitation data [77]

The **Structured Implementation and Information Framework (SIIF)** concept is an ongoing European Commission (Environment Directorate General) project essentially focused on the organization and management of data in order to enhance the generation of information for policy makers, interested parties and the public at all levels on how legislation is practically implemented. The concept developed is in line with the provisions of the Public Access to Environmental Information and INSPIRE Directives.

The SIIF concept is composed of a governance approach and an IT system. The SIIF implies governance focused on compliance, good environmental status, environmental pressure and impact, economic activities, and job creation. It also has an objective to reduce the administrative burden, provide more up-to-date data, and increase efficiency for all potential users. Providing an implementation programme on how to reach or maintain policy compliance is also part of the SIIF governance approach.

The SIIF's IT system features three components: (1) content for the data community (information needs and how they are organized); (2) the process for data providers (who does what and how); (3) dissemination for data users (how to display). All of these components have a national and European dimension.

This IT development is related to the process and dissemination of the existing content of the European urban waste water data model.

The SIIF project opted to implement an open-source IT toolbox. The tool was designed to disseminate environmental data and information at national level but also to facilitate the reporting process. It provides EU Member States with a cheap way to implement Article 11 of the INSPIRE directive, and thus to develop a national waste water website. The framework of this website can also be adapted to correspond to other European Policies.



Figure 59: Cover page of the UWWT SIIF European node

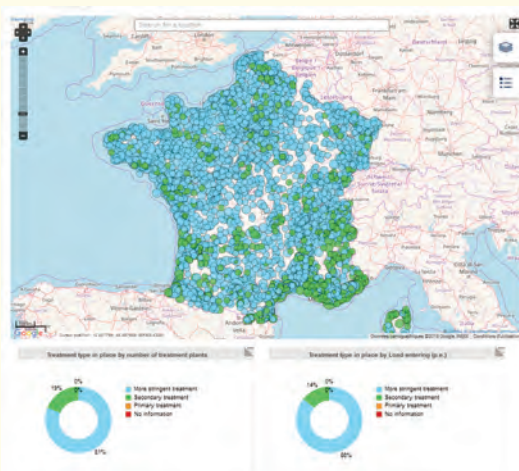


Figure 60: Urban waste water treatment plants in France

4.7 Water information systems for transboundary basins

KEY POINTS

- The data management difficulties encountered for national IWRM are exacerbated in a context of transboundary water resource management.
- Transboundary platforms should allow sharing comparable data answering to the needs.
- Facilitating data and information exchange between riparian countries helps to build cooperation and trust.

4.7.1 Stakes and data/information needs for transboundary basins

Managing water resources in transboundary basins requires sharing data and information that meets the expectations of stakeholders for various activities: planning, monitoring, and assessment, prevention and alerts, etc.

Unfortunately, the exchange of information and data on a transboundary basin is often difficult, both for structural reasons (when there is no agreement or protocol between the countries to do so), and for technical reasons (difficulties related to information collection, harmonization of data formats, definitions, analysis methods, frequency of data collection, density of monitoring networks and data processing).

As well as standard difficulties (data that is dispersed, heterogeneous, incomplete and rarely comparable), more generally, national authorities may be reluctant to provide neighbouring countries with information that they consider strategic. In addition, the economic value of water used for hydropower, agricultural irrigation and navigation may increase this reluctance.

Information systems are thus key instruments for the development of integrated management of transboundary basins: they are tools designed to facilitate the production and sharing of information expected by stakeholders. Given the situation, their development requires working firstly on institutional, organizational and governance issues, and secondly on technical issues related to the construction of the information system. At the organizational level, it is necessary to have prior confirmation of the political will to work together in order to produce shared information, and then to agree on the governance framework and organize the system's development in close cooperation with stakeholders to continuously look for "win/win" solutions. At the governance level, the transboundary basin organization, when there is one, is usually in charge of developing the information system. It can also manage the system, and play a facilitator role in working groups established to produce and share information.

From a technical point of view, the information system must be built by seeking above all to facilitate the production and availability of information useful for decision-making. Wherever possible, it should rely on clearly identifying information needs and enhance the national information systems and datasets made available by partners by developing capacities to exchange comparable data and interconnect the partner information systems (interoperability), using common language (concepts/referential dataset) and common procedures.

Working on a transboundary water information system can help to develop cooperation and build trust in shared data and information.

4.7.2 Case studies

Case study 45: Water Information Systems facilitating transboundary management in the Rhine river basin [78]

The International Commission for the Protection of the Rhine (ICPR) develops, manages and uses different types of Water Information Systems (WIS) that are essential tools for the cross-border exchange and compilation of data within the Rhine river basin. However, the prerequisite for all (virtual) water information systems remains a real, well-organized exchange between the working bodies of the ICPR, whose members collect and produce complex data related to water quality and quantity issues. The various stages of the work between the countries within the Rhine basin are supported and accompanied by computer-, model- and GIS-based information systems presented here.

For the purpose of data management related to the implementation of both the European Water Framework Directive and the Floods Directive within the Rhine basin, the ICPR has concluded a cooperation agreement with the German Federal Institute of Hydrology (BfG) comprising the use of the water portal “WasserBLiCK” (data exchange and hosting platform) and the production of different maps for the general and specialized public. Rhine Warning and Alarm Plan

After the chemical accident at Sandoz in 1986, the ICPR strengthened its international Warning and Alarm Plan (WAP). If, despite all preventive measures, an accident occurs or great amounts of hazardous substances flow into the Rhine that may detrimentally impact the water quality or drinking water supply along the river, the model-based WAP is activated, which above all warns all users downstream. Apart from warnings, which are only issued by the International Main Alert Centres (IAC) during huge and serious water pollution events, the WAP is increasingly used as an instrument for exchanging reliable information on sudden water pollution measured by monitoring stations along the Rhine, Neckar and Main rivers and smaller tributaries. The warnings and information issued every year are compiled in an annual report available on the ICPR website.

Transboundary Information systems related to flood risk management

The “Rhine Atlas” is a supra-national sensitization tool comprising aggregated flood hazard and risk maps of the countries on the river. For the main stream of the Rhine, flood depth and areas as well as objects at risk are shown for three scenarios (high, medium and low flood probability). Additional information and more detailed national maps are available by clicking on any area of the atlas. The Rhine Atlas, which is available on the ICPR website, raises risk awareness, supports the implementation of preventive measures in flood-prone areas, and represents a database for risk calculations (see below, the tool ICPR FloRiAn).

Flood forecasting and flood announcement contribute to reducing damage in case of a flood event. Therefore, the Rhine countries – through national centres along the river - cooperate at international level when exchanging data on discharge and precipitation and using them for flood forecasting. The quality of information and forecasting is continuously being improved. Today, national mobile applications like “Meine Pegel” (my gauges) disseminate information and warnings on water levels.

Instrument for assessing the impact of flood risk management measures on risk evolution: The ICPR, supported by the engineering consultant HKV, developed the GIS instrument “ICPR FloRiAn (Flood Risk Analysis)”. Its purpose is to evaluate the effect of measures to reduce flood risk and estimate the future evolution of flood risk. Flood maps (e.g. developed under the FD) are the basis for the tool. In addition to the quantification of economic flood risk, modules are developed for quantifying the consequences of risks for human health, the environment and cultural heritage. In short, the main instrument consists of three interacting calculation modules resulting in an overall damage or risk assessment. The ICPR uses this tool to assess risk reduction and evolution along the Rhine taking into account the impacts of measures. The instrument is available on demand from the ICPR and is applicable to other river basins.



Figure 61: The International Main Alert Centres (IAC) and information flow



Figure 62: Rhine Atlas (flood hazard and flood risk maps)

Case study 46: Transboundary Sava River Basin / Sava GIS - GeoInformation System for the Sava River Basin [79]

The International Sava River Basin Commission (Sava Commission), in cooperation with relevant national institutions from the Sava River Basin under the Framework Agreement for the Sava River Basin (FASRB), established a joint platform called the Geo-Information System for the Sava River Basin (**Sava GIS**) in 2016. The overall objective of Sava GIS is to provide good communication channels for the Sava Commission community in order to share and disseminate information and knowledge about protection of water resources and water management activities in the Sava River Basin. It also facilitates the exchange and use of hydrological and meteorological information and data through its component, the Hydrological Information System (**Sava HIS**).

Sava GIS strongly supports Sava riparian countries in attaining the EU environmental acquis in the field of water management. The specific objectives of Sava GIS are to provide support and assistance to the Sava Commission and basin countries for river basin management planning and all joint activities targeted for the EU WFD planning cycles, as well as specific activities in the flood risk management planning foreseen by the EU FD.

The database models for the River Basin Management and Flood Risk Management were designed and structured in accordance with the related EU directives: the INSPIRE Directive and professional requirements, WFD Reporting Guidance and FD Reporting Guidance. The plan is to expand this component for all other ISRBC benefit areas (navigation management, sediment management, accident pollution prevention and control). The Sava GIS Geoportal is a scalable and flexible tool that implements open source technologies. The focus of the Sava Geoportal is data visualization and management as well as open web services like WFS and WMS. Once the system is fully functional, interested parties (government institutions, private entities, general public, etc.) will be able to view available datasets through the Sava Geoportal and its submodules (Metadata Catalogue, Sava HIS). The Sava GIS Geoportal can be reached at: <http://savagis.org/>. A web application for editing, loading and retrieving data and metadata allows registered users to view, visualize, share and retrieve geographic information and datasets stored in the database for the whole basin.

Sava HIS, as the Sava GIS component, represents a tool for collecting, storing, analyzing and reporting sufficiently high-quality hydrological and meteorological data. The overall objective of Sava HIS is to support Sava countries in sharing and disseminating hydrologic and meteorological

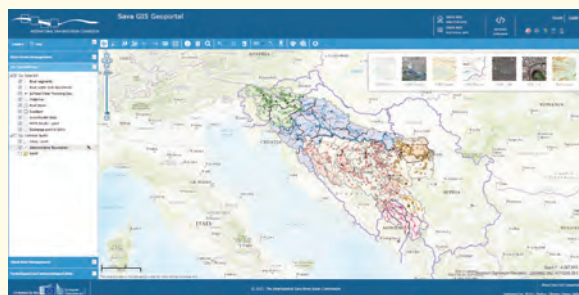


Figure 63: Screen shot of the Sava GIS

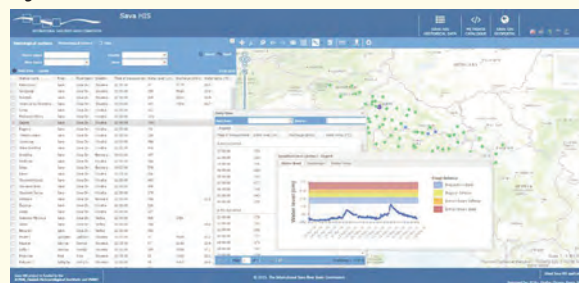


Figure 64: Screen shot of the Sava HIS

data, information and knowledge about water resources in the Sava River Basin. These data and information are used by decision-making systems in all aspects of water resources management, especially flood risk management and forecasting, and in a wide range of operational applications and research. Since the WaterML 2.0 format is implemented in Sava HIS, the WMO exchange standard, the system can store water observation data and spatial information, shared by countries, in a standard format. It also supports data sharing and publication via web services for further use. A specific part of Sava HIS is dedicated to real-time data exchange for which a separate web application is available at:

<http://savagis.org/>.

Case study 47: African Water Documentation and Information System (AWIS) [17]

Access to information on the African water sector



The African Water Documentation and Information System (AWIS) is an initiative launched in 2007 by a group of institutions from the North and South: CREPA (Regional Center for Water Supply and Sanitation), OMVS (Organization for the Development of the Senegal River) through ANBO (African Network of Basin Organizations), pS-Eau (Water Solidarity Program), IOWater (International Office for Water) and WEDC (Water Engineering and Development Centre).

AWIS aims to build the information management capacity of organizations in the African water sector through sharing knowledge, experience and information between water professionals, communities and local and national governments on a pan-African scale.

AWIS is a strategic tool of ANBO (African Network of Basin Organizations), and provides a management platform of information and knowledge on the scale of Africa.

The targets of the ANBO resource centre are operational actors of public policies involved in water resource management: ministries (central, decentralized), basins, organizations, associations, socioeconomic actors, education / training organizations, water users, local communities and consumer authorities.

5 Conclusions and perspectives

Considering the growing challenges facing water resources management, access to information concerning the status and evolution of the water resource and its uses is a crucial component of water policy. Water resource administrators responsible for regulatory actions, planning, risk management and informing the public need reliable, up-to-date and pertinent information to make sound decisions in water management.

Data and information can be now accessed through computers, tablets and smartphones, even in the most remote locations, and end-users increasingly demand easy access to data and information that is understandable and adapted to their needs.

Unfortunately, the necessary data are often produced and managed by disparate organizations in different sectors, with little coordination among themselves.

Numerous systems and data already exist, but in many cases, professionals and decision-makers still lack crucial data, and the plethora of sources makes it difficult to identify the most appropriate datasets, and to assess the quality of the information provided.

Thus, efforts must be increased to organize access to water-related data and information in an effective and sustainable way, combining all possible comparable and quality-controlled data sources, using procedures and tools adapted to needs.

This handbook underlines why water data management is so important for efficient water resource management and introduces **five main processes to be considered when implementing a Water Information System (WIS)**, i.e. **data governance; data production; integrated data management and data sharing between institutions; data processing and information production; and information dissemination.**

It also presents a picture of the main challenges and some case studies showing how information systems are implemented to answer needs in various water sector management domains, such as: IWRM water planning, climate change adaptation, flood management, water and ecosystem protection, sectoral water use management (agriculture, drinking water, energy production, etc.), data for reporting, and transboundary water resources management.

Looking to the future, it is clear that the world of information systems is constantly changing: cloud computing, service-oriented architectures, artificial intelligence, web services, Internet of things, open data, interoperability, big data, 3D visualization, exploitation of social networks etc.

Moreover, data sources are also expanding (satellite data, communicating objects, crowd sourcing, etc.) and the fields of application are evolving, in particular with the needs of adaptation to climate change.

All water management sectors can benefit from these innovations with a real positive return on investments: this requires **adapting governance, procedures and tools at all levels** to match needs, and **developing skills and capacities** for facilitating production and access to useful information for decision-making in public information.

Twenty-first century information system technologies open the door to new approaches and solutions: it is up to us to put them to good use to rise to current and future water challenges.



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Access to data and information on the status and evolution of the water resource and its uses is a crucial component for any water policy implementation.

Unfortunately, the necessary data are often produced and managed by several organizations in different sectors, with little coordination among themselves and in many cases the information available for decision making and public information is not fully adapted to the needs.

Today, efforts must be increased to develop the production and the access to water-related data and information in an effective and sustainable way, developing synergies, combining the various resources and data sources, and using procedures and tools adapted to needs.

To support this process, INBO and UNESCO, with the World Meteorological Organization (WMO), the Australian Bureau of Meteorology coordinating the World Water Data Initiative (WWDI) and the International Office for Water (IOWater), have joined forces to write this handbook.

This document underlines why water data management is so important for efficient water resource management and introduces the main

processes to be considered when implementing a Water Information System (WIS), including data governance; data production; integrated data management and data sharing between institutions; data processing and information production; and information dissemination.

It also presents a picture of the main challenges with some case studies showing how information systems are implemented to meet needs in various water sector management domains, such as: IWRM water planning, climate change adaptation, flood management, drought forecasting, water resources and ecosystem protection, sectoral water use management (agriculture, drinking water, energy production, transport, industry, fishing, etc.), data for reporting, and transboundary water resources management.

This handbook is addressed to water-sector decision-makers and to those interested in developing their capacities for producing, accessing, processing and making good use of the water-related data and information necessary for implementing an Integrated Water Resources Management policy at basin, national, transboundary or regional level.

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