Australian Government
Bureau of Meteorology

GOOD PRACTICE GUIDELINES FOR WATER DATA MANAGEMENT POLICY

WORLD WATER DATA INITIATIVE

WORLD
METEOROLOGICAL
ORGANIZATION

Published by the Bureau of Meteorology
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An appropriate citation for this publication is:
Bureau of Meteorology, 2017. Good practice guidelines for water data management policy: World Water Data Initiative. Bureau of Meteorology, Melbourne.

Cover photograph: Lake Weyba, Queensland (iStock © CUHRIG)

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ACKNOWLEDGEMENTS

1.1 HIGH LEVEL PANEL ON WATER

This report has been prepared under the World Water Data Initiative, on behalf of the United Nations and World Bank High Level Panel on Water.

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The publishers gratefully acknowledge the assistance of Akvo; Australian Water Partnership; Bremen Overseas Research and Development Association; CDP; Center for Water Security and Cooperation; CGIAR; Circle of Blue; Committee on Earth Observation Satellites; Commonwealth Scientific and Industrial Research Organisation (Australia); Data4SDGs; Department of Foreign Affairs and Trade (Australia); European Space Agency; Food and Agriculture Organization of the United Nations; Gates Foundation; Geoscience Australia; Global Environment Facility; Global Innovation Fund; Global Runoff Data Centre; Google; Group on Earth Observations; High Level Panel on Water; International Food Policy Research Institute; International Fund for Agricultural Development; International Groundwater Resources Assessment Centre; International Network of Basin Organizations; International Union for Conservation of Nature; International Water Management Institute; International Water Resources Association; Morgan State University; National Aeronautics and Space Administration (USA); National Oceanic and Atmospheric Administration (USA); Organisation for Economic Co-operation and Development; Oxford University; Partenariat Français pour l'Eau; R4D – Results for Development; Ramsar; Texas A&M University; The Nature Conservancy; United Nations Children's Fund; United Nations Department of Economic and Social Affairs; United Nations Development Programme; United Nations Educational, Scientific and Cultural Organization (UNESCO – IHE, UNESCO-IHP); United Nations Environment Programme; United Nations Global Compact; United Nations University – Institute for Water Environment and Health; United States Agency for International Development; United States Geological Survey; University of Maryland; University of Nebraska; UN-Water; WellDone.org; WHO/UNICEF Joint Monitoring Programme; Women for Water Partnership; World Bank; World Economic Forum; World Meteorological Organisation; World Resources Institute; World Water Council; World Wildlife Fund.

EXECUTIVE SUMMARY

Detailed analyses done by the World Bank[1], Asian Development Bank[2], OECD[3], United Nations[4] and World Economic Forum[5] rate water security as one of the risks and strategic challenges confronting humanity. This is due to a serious and worsening supply/demand imbalance caused by rapid population growth and industrialisation, over-extraction of water, widespread pollution and climate change. Today, more than 1.8 billion people globally source some of their drinking water from contaminated sources and a further 2.4 billion people lack access to safe sanitation services, resulting in the entirely preventable deaths of nearly 1,000 children daily.[6] Deteriorating water security poses grave threats to the global economy and to regional security. It is estimated that more than USD$20T will be invested in water infrastructure globally by 2050 (excluding investments in irrigation and energy)[7]. That financing challenge is massive, but so too are the crucial challenges of improving the governance and technical capacity of the countries facing the biggest water sector changes.

The High Level Panel on Water (HLPW), jointly convened by the United Nations and the World Bank, recently released a Water Action Plan[8], setting out a detailed approach to the steps that need be taken to avert a future global water security crisis. The Water Action Plan emphasises that much will need to be put into place, including political leadership, institutional mandates, financing, capacity development and targeted policies and programs.

The HLPW identified access to water data as a key enabling requirement for delivering all other elements of the Water Action Plan. Experience from around the world demonstrates that sustainable water management can only be realized with rigorous evidence-based decision making. That in turn requires a solid information base, and reliable water data is a vital pre-requisite for this.

1 http://www.worldbank.org/en/topic/water/overview
2 https://www.adb.org/publications/asian-water-development-outlook-2016
3 https://www.oecd.org/environment/resources/Water-Growth-and-Finance-policy-perspectives.pdf
4 http://www.unwater.org/app/uploads/2017/05/analytical_brief_oct2013_web.pdf
5 http://reports.weforum.org/global-risks-2017/
6 http://www.un.org/sustainabledevelopment/water-and-sanitation/
7 https://www.oecd.org/environment/resources/Water-Growth-and-Finance-policy-perspectives.pdf
8 https://sustainabledevelopment.un.org/content/documents/11280HLPW_Action_Plan_DEF_11-1.pdf

However, "getting water information right" is a major challenge, requiring careful planning, sensible investment and diligent execution of strategy. These *Good Practice Guidelines for Water Data Management Policy* have been prepared to assist officers responsible for formulating and implementing government strategy to improve water information, with the aim of advancing water policy, planning, management and operations. The guidelines describe the various high value uses of water data and identify seven elements to good practice in water data management. These include (1) identifying the priority water management objectives, (2) strengthening water data institutions, (3) establishing sustainable water data monitoring systems, (4) adopting water data standards, (5) embracing an open data approach to water data access and licensing, (6) implementing effective water data information systems and (7) employing water data quality management processes.

Each agency in each country will have a different capacity to achieve good practice, governed by their existing water management challenges, technical capacity, financial resources, public administration arrangements and political support. Those with the most to achieve will likely be the ones that will need to take modest initial steps.

What is most important is starting the reform journey and demonstrating the benefits that can be gained by improving water data management arrangements. This will help to build trust, then belief and eventually support. Hence, it is important to take a long-term, strategic view of the reform process and resist the temptation to over-promise what can be accomplished, particularly if resources and capacity are limited. Suffice it to say, the chances of success will be vastly improved if the proposed reforms are carefully planned, diligently executed and the resulting benefits clearly articulated.

These guidelines acknowledge that it is difficult to gather support for and then prosecute actions that are disruptive to the status quo and requiring considerable public investment. It is stressed that planning the water data reform journey is every bit as challenging as implementing the reforms themselves. Accordingly, these guidelines conclude with a recommended series of steps to get started in reforming water data management arrangements. Guidance is provided for (1) taking stock of current policy settings, (2) preparing the case for reform, (3) positioning for effective implementation and (4) championing the reforms.

1 INTRODUCTION

1.1 BACKGROUND

These good practice guidelines for managing water data have been prepared as part of the work program of the High Level Panel on Water (HLPW). The HLPW includes eleven Heads of State and Government, and was convened in 2016 by the United Nations Secretary General and the World Bank Group President[9]. The panel was formed to promote implementation of the United Nations Sustainable Development Goals on Clean Water and Sanitation (referred to as SDG-6)[10].

Under the SDG-6 goals, member states of the United Nations have committed to *"ensure availability and sustainable management of water and sanitation for all by 2030"*. This is a very large task as the world faces significant water challenges today and well into the future. Today, billions of people around the world still lack access to adequate clean water and sanitation, consigning them to lives of poverty, disease and civil strife. The global scarcity of water is also holding back global economic growth and threatens regional security. On our current path, the world is estimated to face a 40% shortfall in water availability by 2030, and water scarcity is expected to be a significant brake on economic growth.

9 https://sustainabledevelopment.un.org/HLPWater
10 https://sustainabledevelopment.un.org/sdg6

The HLPW Action Plan[11], released in September 2016, sets out a detailed approach to the steps that need be taken to avert a future global water security crisis. The Action Plan emphasises that much will need to be put into place, including political leadership, institutional mandates, financing, capacity development and targeted policies and programs. The HLPW identified access to water data as a key enabling requirement for delivering all other elements of the Action Plan.

In February 2017, the HLPW released the World Water Data Initiative Roadmap[12]. The stated objective of that initiative is "*To improve cost-effective access to and use of water and hydro-meteorological data by governments, societies and the private sector through policy, innovation and harmonisation".* The initiative roadmap sets out three pillars of work that will contribute to this objective, including (1) making advancements in water data policy, (2) water data innovation and the (3) harmonisation of water data access, exchange and metrics.

The advancement envisaged under the water data policy pillar is *"To address the question: how can societies have better and more equitable access to water data and tools, and capacity to use this information, to manage water better?".* In pursuit of this objective, the roadmap calls for the preparation of *"good practice guidance materials to highlight the benefits of equitable access to water data and demonstrate good practice principles and tools for the collection, storage, analysis and use of data, and the information derived from it, that would be capable of universal adoption and application."*

11 https://sustainabledevelopment.un.org/content/documents/11280HLPW_Action_Plan_DEF_11-1.pdf
12 https://sustainabledevelopment.un.org/content/documents/13327HLPW_WWDI_Roadmap.pdf

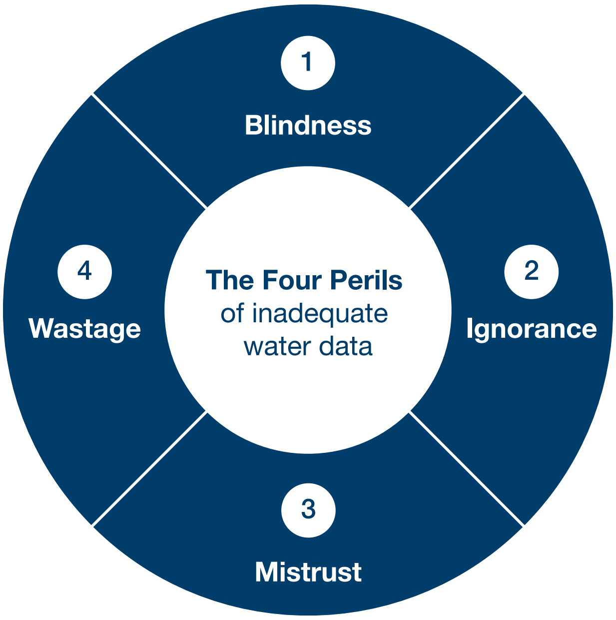
1.2 THE FOUR PERILS OF INADEQUATE WATER DATA

Around the world, water sector participants are expressing frustration that their nation's water data arrangements are not meeting their needs. This is often despite the urgency to tackle profound and worsening water management problems. Data is gathered by many actors but not openly shared. There are many gaps in the water data information base. The quality of the data is uneven and often poor. Even the good data that is available is rarely made into a form that encourages objective decision making. Those facing impending water crises agree that valuable time is being lost arguing over data instead of debating the merits of different policy responses.

Together, these annoyances form a very challenging problem. Put simply, in many countries, water data is not being used to improve public understanding of the water situation and to support decision making. Given that substantial reforms take years to implement, such countries are now urgently seeking solutions to redress *the four perils* of inadequate water data.

The first of these perils is 'blindness'. Without good water data one cannot see where they have come from and where they are going. In this situation, water shocks always come as surprises and governments are ill-prepared to mitigate their impact.

The second of these perils is 'ignorance'. A water data vacuum allows poor policy ideas to have a false equivalence to good ones. Policy makers are unable to make wise choices because the supporting information is unreliable at best and contradictory at worst.



The third of these perils is 'mistrust'. When water is scarce, access to it is keenly contested. The risk of conflict over access to water is always present but magnified by inadequate water data. The absence of facts breeds mistrust, between agencies, industries, provinces and even neighbouring nations. Such mistrust makes policy responses to water problems so much more difficult to implement.

The fourth of these perils is 'wastage'. Massive investment goes into water infrastructure and this supports enormous social and economic value creation. However, if water resource allocation, condition and use is not properly monitored and evaluated, then the input investments and potential resulting benefits are vulnerable to wastage.

1 INTRODUCTION

Experience from around the world demonstrates that sustainable water management can only be realized with rigorous evidence-based decision making. That in turn requires a solid information base, and reliable water data is a vital pre-requisite for this. As such, water data is an essential, strategic investment in managing humankind's most vital resource.[13]

Investments in water data have been shown to yield very positive financial returns, via significant mitigation of disaster risk, improvements in water use efficiency and cost effective design of water infrastructure[14]. However, "getting water information right" is a major challenge, requiring careful planning, sensible investment and diligent execution of strategy.

13 See Walker (2000) The value of hydrometric information in water resources management and flood control. Meteorol. Appl. 7, 387–397, available online at http://onlinelibrary.wiley.com/doi/10.1017/S1350482700001626/pdf

14 See Centre for International Economics (2015) Economic analysis of the Bureau of Meteorology's water information. Internal report for the Australian Bureau of Meteorology, available upon request.

1.3 PURPOSE OF THESE GUIDELINES

These good practice guidelines are intended for officers responsible for formulating and implementing government strategy to improve water information, with the aim of improving water policy, planning, management and operations. These officers may come from a variety of fields, including hydrology, information technology, business process improvement and central government. Their collaborators, from the private sector and the research sector, as well as donor agencies, are also an important audience for these guidelines.

Each country and its various water agencies will be at a different state of development with regard to their water data management arrangements. Those with some of the most severe water problems will typically be the ones with the greatest need to improve their water data. These countries are also likely to be the ones that will face the greatest challenges in implementing good practice water data management, owing to their lesser resources, supporting IT infrastructure and technical capacity.

Investments in water data have been shown to yield very positive financial returns, via significant mitigation of disaster risk, improvements in water use efficiency and cost effective design of water infrastructure. However, "getting water information right" is a major challenge, requiring careful planning, sensible investment and diligent execution of strategy.

Donor agencies can help to alleviate these problems, but resourcing and capacity limitations will be common, requiring a thoughtful approach when considering these good practice guidelines. It is not expected that all countries can implement these good practice guidelines in full. However, there are many elements of good practice that can be adopted by all. Experience shows that progress in water data management practice will be maximised with clear problem definition and astute investments directed at the highest priority water information needs.

1.4 SCOPE AND LIMITATIONS

These guidelines are focused on national, basin and transboundary water resources. They are primarily concerned with their biophysical aspects, though some administrative data is also touched on. There are important types of socio-economic data relevant to water management that are not addressed in these guidelines. These include water demand information and economic data on agricultural and industrial production from water dependent enterprises. Other types of information include data on populations, health, employment, income and gender. Such contextual information is often critical for preparing and evaluating water policies and associated water management arrangements. Much of this kind of data is collected by national statistical agencies and collated and analysed at the international level by organisations such as UN-Water and FAO.

2
USES OF WATER DATA

2.1 INTRODUCTION

Across the broad areas of water policy, water planning, water management and water operations, there is a wide variety of uses for water data. Whilst different countries will certainly have different requirements, there are seven basic uses for water data that most countries are likely to have in common (see Figure 2.1).

2.2 WATER ASSESSMENT

The critical first step in Integrated Water Resource Management (IWRM) is describing the water resource and its use in the planning area of concern. Doing so provides a solid, facts-based foundation for stakeholder consultation, which is seminal to IWRM. Water Assessment is the process of dimensioning the water resource and how it is utilised. It is crucial for illuminating the dynamic nature of water resources, brought about by continuous changes in water supply and demand.

Water data provides an objective basis upon which to answer important water assessment questions such as:

- Do we have sufficient water resources to meet all of the demands that exist?
- How have patterns of water use varied over time and how do they differ between regions?
- Is the amount of water in our reservoirs, rivers and aquifers lower or higher than usual for this time of year?
- Are the recent declines in rainfall and runoff during the current drought more extreme than during prior droughts and do water allocation and management policies need to be modified to allow for such extremes?
- Which parts of the country are suffering the most acute water shortages and why?
- Is the frequency and severity of flooding in my region increasing or decreasing?

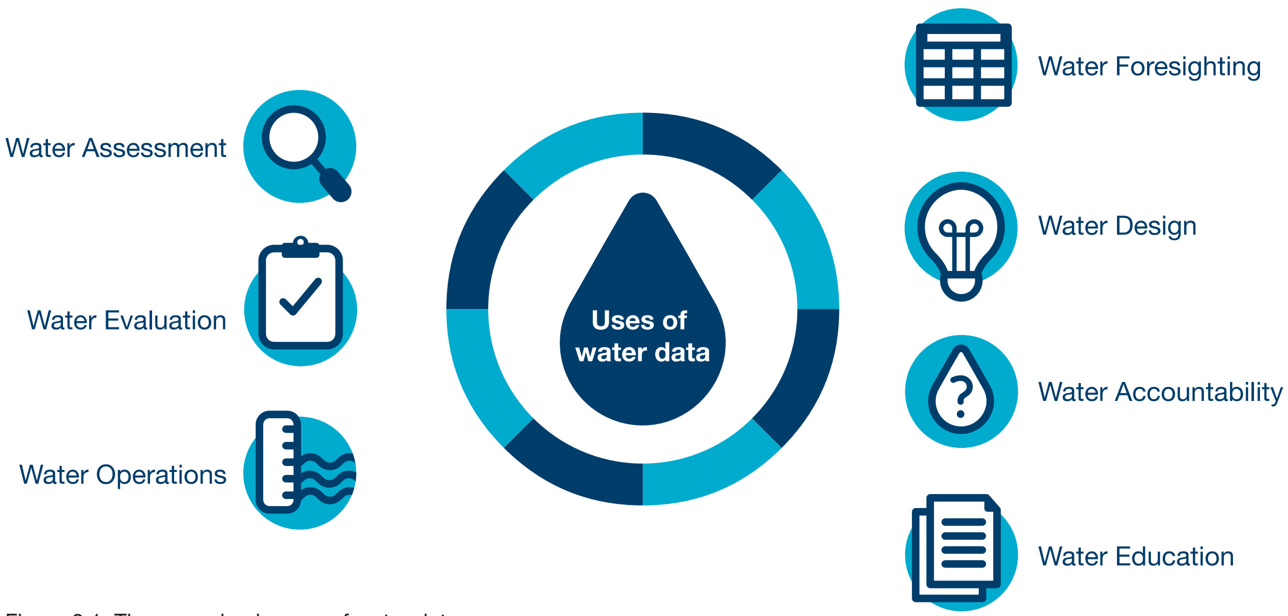
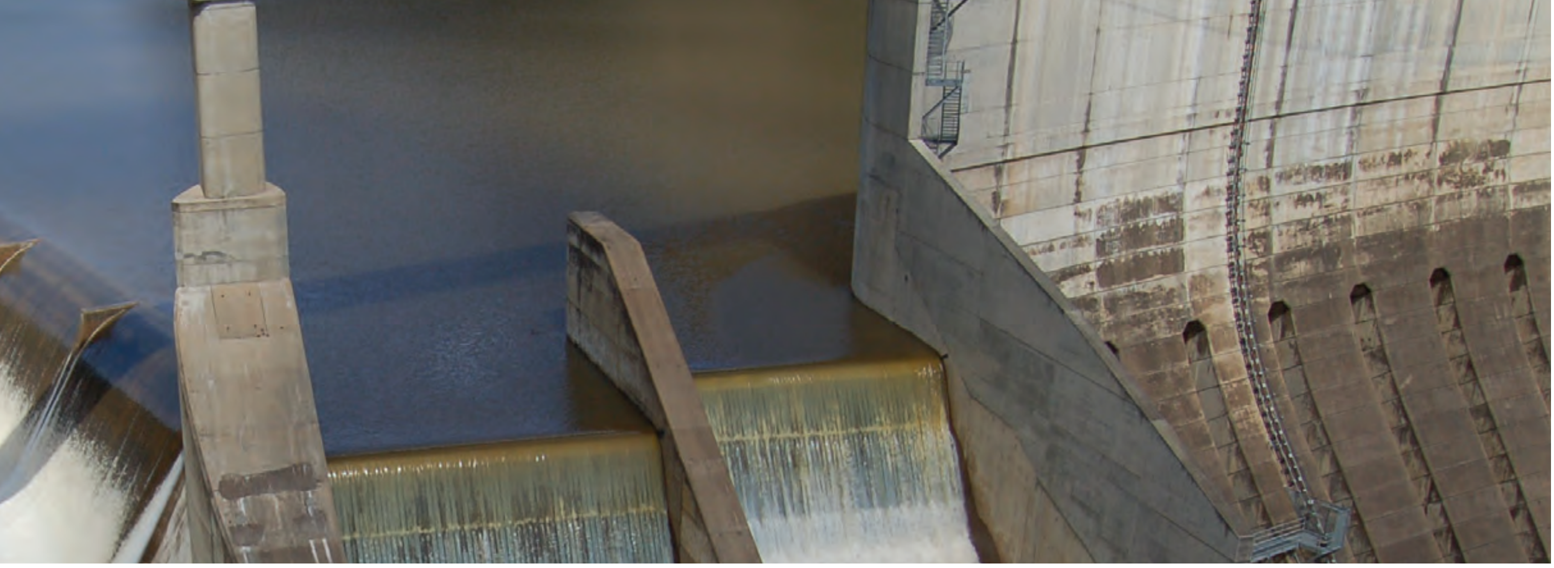


Figure 2.1: The seven basic uses of water data



2.3 WATER EVALUATION

Water Evaluation is the process of judging the efficacy of water policy settings and management interventions. This is another very important aspect of IWRM, providing water stakeholders with a feedback loop to help continuous improvement. Examples of interventions that might be the focus of an evaluation process include changes to river and reservoir operating procedures, new land management strategies, the reallocation of water rights amongst different users, the imposition of water use restrictions and the introduction of water trading. Water data provides an objective basis upon which to answer important water evaluation questions such as:

- How have basin water sharing arrangements affected the relative water security of upstream and downstream users and ecosystems?
- Has the imposition of mandatory water metering reduced the extraction of water from rivers and aquifers?
- Has the introduction of water trading in my region enabled irrigators to maintain their economic output during drought periods?
- Has the adoption of more conservative water allocation rules improved or degraded the risk/reward balance for farmers in my region?
- Have changes to land cover and land use in my basin affected the water quality in the rivers of my region?

For water evaluation exercises it will often be necessary to have access to complementary socio-economic data collected by statistical agencies and others.

2.4 WATER OPERATIONS

Water Operations refers to the real-time monitoring of water data parameters for the purposes of operating water infrastructure such as reservoirs, weirs, pipelines and irrigation canals. One example is safe reservoir operations during a major rainfall event. In this situation, the water data parameters that would need to be monitored in real time include the water level in the reservoir, the inflow volumes from the upstream tributaries, the outflow volume from the reservoir and the water level at various points along the river course downstream of the reservoir. Other examples might relate to operating water distribution networks in irrigation districts and cities, where it is critical to monitor changes in pressure head at various points across the network. Measuring such data in real time provides an objective basis upon which to answer important water operations questions such as:

- Given the current rates of inflow, how long will it take for the reservoir to fill during this rainfall event?
- Given the downstream conditions, what is a safe rate of release of water from this reservoir?
- How close is the river to overtopping its banks at various points downstream?
- How much water must be diverted into the canal system to satisfy all of the known irrigation demands?

2.5 WATER FORESIGHTING

Water Foresighting is the process of estimating how our water resources and the way we use them are likely to change in the future. Foresighting processes are quite varied, but include near term assessments based on very specific forecasts, medium term assessments based on more generalised probabilistic outlooks, and long term projections based on more speculative scenario analyses. In each of these situations however, water data is crucial for parameterising and validating the predictive models used in the foresighting process. Water data, when combined with predictive models, provides an objective basis upon which to answer important water foresighting questions such as:

- What will be the maximum level of the flood in my town for this current storm event and at what time will it occur?
- How available will water be in the coming growing season and how might that affect the price of water on the water trading market?
- How likely is it that the reservoirs in my region will run out of water in the next two years?
- How will demand for water in my region change over the next two decades given recent trends in population growth and water use behaviour?
- How will climate change over the next half century affect the amount of rainfall in my region and what impact will that have on basin water supply?

2.6 WATER DESIGN

Water Design is the process of determining the appropriate design parameters for water infrastructure. This could include selecting the most appropriate type of infrastructure, estimating its optimum size and performance characteristics, and determining the most appropriate timing for its introduction. Water data provides an objective basis upon which to answer important water design questions such as:

- How big should we make this drain so that it is able to pass flows generated from a 1 in 100 year rainfall event?
- How high do we need to make this river levee bank to protect our town from flooding?
- What size water reservoir is required to provide a reliable supply of water to my region and control severe flooding?
- Given estimated trends in population growth, water use behaviour and climate change, when will we need to augment our town water supply and by how much?
- When augmenting our town water supply next, should we build another dam, increase groundwater extractions, or introduce a climate resilient water source such as desalination or water recycling?

2.7 WATER ACCOUNTABILITY

Water Accountability is the process by which water managers build trust with customers, investors, regulators, the community and other stakeholders. Significant responsibility is vested in water managers to deliver citizens, businesses and ecosystems adequate supplies of safe water efficiently. Transparency in the activities of water managers helps build the trust of stakeholders, particularly in situations where water scarcity creates competition for access to water and necessitates significant changes in water management arrangements. Examples of important water accountability questions include:

- How much water is being used by each of the user groups in my basin?
- Does the quality of the drinking water supplied in my region always meet national standards and how does it compare to other regions?
- How efficient is the irrigation system in my region compared to others?
- How are water allocation policies affecting my industry's access to water?
- Is my region subject to more or less water restrictions than other regions and is there as case for augmenting supply?

2.8 WATER EDUCATION

Water Education is the process of enabling communities to understand where our water comes from, how it is managed and how it is used. Communities with high levels of 'water literacy' tend to value water, conserve water and support government policies and programs to improve water management. Water data can be used to build water literacy in the community by helping to answer common questions such as:

- What are the various sources of water supply in my region?
- How is water in my region used and by whom?
- What economic benefits are derived from the use of water?
- Which ecosystems depend on water for their survival?
- How is water treated and delivered to users and what becomes of wastewater?

It is likely that most countries will use water data for all of these purposes, but it is helpful to be explicit about why water data is needed. In Chapter 5 of these guidelines, emphasis will be placed on the criticality of defining the priority water management objectives in framing strategy around water data management arrangements.

3
TYPES OF WATER DATA

3.1 INTRODUCTION

There is no single definition for the term water data, which potentially encompasses a large number of physical, chemical, biological, social, economic and administrative variables related to water and water management. The definition adopted in these guidelines is confined to the types of variables required for the seven primary uses of water data described in the previous chapter of these guidelines.

3.2 WATER DATA GROUPS

Table 3.1 lists twelve broad groups of water data and for each group, provides examples of the often parameters required by water managers. The availability of these kinds of water data parameters enables water managers to assess the security and condition of water resources and how they are being accessed and utilised.

No.	Water data parameter groups	Examples of water data parameters for each group
1	Meteorological data	Rainfall, wind speed, humidity, temperature, radiation, evaporation
2	River data#	River water level, river discharge, flood inundation area and depth
3	Groundwater data#	Groundwater level and pressure, aquifer thickness, permeability and storage capacity
4	Water storage data#	Water storage bathymetry and level, accessible storage volume, storage inflows, outflows and offtakes
5	Water use data	Water taken from rivers, groundwater and storages, water applied to various economic and environmental uses
6	Water quality data	Electrical conductivity, suspended sediment, nutrients, temperature, pH, oxygen
7	Water pollutant data	Concentrations of arsenic, bacteria, viruses, fertilizers, pesticides, algae, industrial waste
8	Waste water data	Volume of sewage and stormwater generated, treated and returned to the environment
9	Manufactured water	Volume of potable and non-potable water derived from desalination, recycling and stormwater harvesting schemes
10	Ecosystem data	Lakes, wetlands, springs, caves and associated water dependent ecosystems
11	Water rights data	Water ownership, water license conditions, temporary and permanent water transfers, water restrictions
12	Administrative data	Water prices, water management area boundaries, water access and sharing rules, water infrastructure inventories

Table 3.1: Groups and examples of water data parameters. For parameter groups marked with #, see also water quality and water pollutant parameters.

3.3 WATER DATA PROVENANCE

Water data is also distinguished by its provenance. There are four broad categories of provenance for water data, including direct measurement, inference from remote sensing, estimation from models and administrative data collection (see Figure 3.1). Each of these categories of water data have issues regarding suitability, accuracy, spatial coverage, temporal frequency and cost. It is important that both the merits and the limitations of each category are understood.

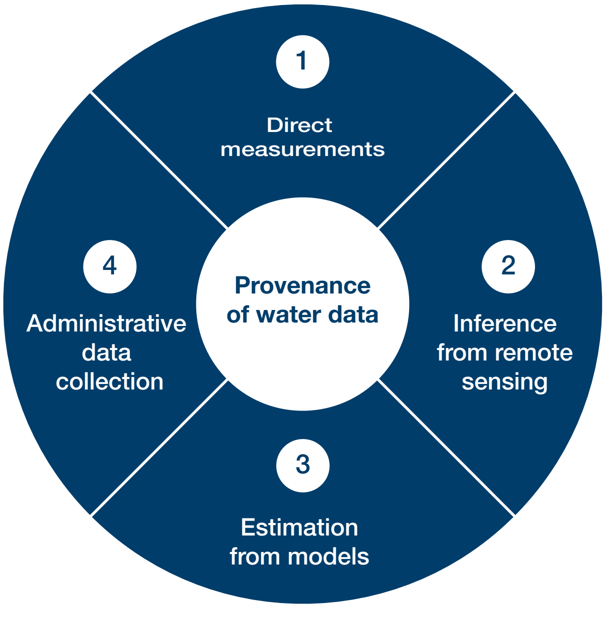


Figure 3.1: The four categories of provenance for water data.

3.4 DIRECT MEASUREMENTS

Direct measurements of water-related variables are mainly obtained from meteorological and hydrologic measurement instruments in monitoring networks, and are the mainstay of water management. A variety of instruments are used to measure most of the physical, chemical and biological water data parameters listed in Table 3.1 (see for instance water data parameter groups 1-10). However, some variables such as river discharge are referred to as 'derived variables' as they are based on a mathematical transformation of a direct measurement. In this example, it is river level that is directly measured and used to derive river discharge based on a modelled level/discharge relationship. For certain types of water data, water samples are collected and submitted to laboratories for physico-chemical analysis.

If made appropriately, direct measurements usually yield the most accurate water data, but they are also the most costly. Although many types of direct measurements of water data are automatic and continuous, the costs involved in equipment purchase, installation, calibration, maintenance and eventual replacement can be considerable. Likewise, the collection of water samples for subsequent laboratory analysis is also costly. Budget limitations will inevitably constrain the size and density of water monitoring networks and the intensity and longevity of associated water sampling programs, limiting the amount of water data coverage in space and time. Hence, directly measured water data usually needs to be supplemented by the other types of water data described below. Nonetheless, direct measurements are an essential part of any water data strategy, providing the most reliable and widest array of water data parameters.

3.5 INFERENCE FROM REMOTE SENSING

Inference from remote sensing involves inferring certain water data parameter values from passive or active remote sensing instruments[15] mounted on satellites, aircraft, drones, vehicles or ground-based structures. Passive sensors include instruments such as radiometers and spectrometers that measure different wavelengths of light reflected or emitted from the observed scene. Active sensors include instruments such as radars and lidars that transmit energy and then measure the time of arrival of the energy reflected back from the observed scene. The quantities measured by these sensors can be related to various water data parameters, such as soil moisture content, rainfall rate, evaporation, the extent of flood inundation, water temperature and the concentration of sediments and nutrients in water. Such inferences can only be made with confidence after careful calibration using direct measurements.

However, once suitable calibrations against ground-based observations are available, remote sensing provides good opportunities for low cost measurements over extensive areas, *albeit* for a limited number of water data parameters. Remotely sensed data is normally presented in gridded form, providing continuous spatial coverage. The temporal frequency of remotely sensed data sets is governed by the type of sensor platform. Satellites provide the most temporally regular data sets, with geostationary satellites providing near continuous data, though at relatively coarser spatial resolution owing to their large distance from earth. Low earth orbiting satellites provide much higher spatial resolution but lesser temporal resolution[16]. A final thing to consider with remote sensing is that significant IT infrastructure is required to handle the large data sets involved and the many complex image processing tasks involved in making the data suitable for use. Much of the complexity can be reduced by accessing ‘ready to use’ imagery from specialised remote sensing centres.

15 For information on sensors, see https://earthobservatory.nasa.gov/Features/RemoteSensing/remote_08.php

16 For information on orbits, see https://earthobservatory.nasa.gov/Features/OrbitsCatalog/

3.6 ESTIMATION FROM MODELS

Estimation from models is necessary when directly measured and remotely sensed water data are inadequate, unaffordable or problematic to measure. Modelled water data will usually be more uncertain than water data derived from direct measurement or remote sensing, but can be immensely useful and is certainly necessary.

Models can be used in a variety of water data management tasks. First, they can be used to fill gaps in water monitoring networks. In any region, it is always the case that only a small percentage of catchments are monitored, yet there is a need to understand how the unmonitored catchments are behaving. Models can be used to estimate how unmonitored areas behave if they can be appropriately calibrated on ‘like’ areas. Second, models can be used to fill gaps in continuous data records. Even in very well monitored catchments, it is inevitable that gaps in data records will occur. Instruments fail, monitoring stations are destroyed by extreme weather events or vandalism, and data is lost. Models, when appropriately trained on continuous data records, are useful tools for filling in such gaps. Third, models are essential to predict future conditions. In general, predictive models perform most reliably when they are well calibrated and applied to conditions reasonably similar to those existing in the calibration record. Predictive models are typically calibrated on one data set, then validated on a separate data set to provide estimates of predictive uncertainty. Finally, models are necessary to synthesise the large amount of complex information that we obtain from catchments. A good example of where models are necessary is in determining how different water sharing arrangements might affect the water security profiles of different water users under various climate scenarios. The number of inputs, controls and feedbacks is very large and models are the only way to integrate the relevant information.

3.7 ADMINISTRATIVE DATA COLLECTION

Administrative data collection is necessary for water data types that are not amenable to direct measurement, inference from remote sensing or estimation by models (see for instance water data parameter groups 11-12 in Table 3.1). This category of water data is very broad and includes information relating to water rights, water pricing, water management regimes, water infrastructure inventories and the use of water in different economic activities. Such information is normally captured by water management agencies as part of their business processes, but some may also be obtained through household and business surveys done by statistical agencies and researchers. Such administrative data is vital contextual information for the development and evaluation of water management strategies and water policy.

3.8 MONITORING THE SDG-6 GLOBAL INDICATORS

A particularly important group of water information that is crucial to achieving the sustainable development goals for water and sanitation is the data used to monitor progress against the SDG-6 targets and global indicators. Whilst this information is not needed for water management purposes per se, it is vital for evaluating whether individual countries are improving water and sanitation outcomes for their citizens. Tracking progress in this way helps to inform donor funding and international capacity building strategies.

UN-Water[17] has recently released a comprehensive guide to the monitoring of the eleven SDG-6 global indicators[18], listed in Table 3.2. Monitoring these indicators entails combining a variety of water data types.

The indicators are chiefly founded on administrative data obtained from household and business surveys, aggregated to the global scale by various agencies such as UN-Water, UNSD, UNICEF, WHO, FAO and the OECD. Some of the key global databases for recording this information are the JMP[19], AQUASTAT[20], IBNET[21], UNSD Environmental Indicators[22], FAOSTAT[23], TWAP[24] and GLAAS[25].

17 http://www.unwater.org/
18 http://www.unwater.org/app/uploads/2016/04/Integrated-Monitoring-Guide-for-SDG6.pdf
19 https://washdata.org/data
20 http://www.fao.org/nr/water/aquastat/main/index.stm
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22 https://unstats.un.org/unsd/environment/qindicators.htm
23 http://www.fao.org/faostat/en/#data
24 http://www.geftwap.org/data-portal
25 http://www.who.int/water_sanitation_health/monitoring/investments/glaas/en/

The indicators also rely on some bio-physical water data obtained by direct measurement and inference from remote sensing that has been aggregated at the global scale. Some of the key global data bases in this category include RSIS[26] for wetlands, the GRDC[27] for river flows and the GGIS[28] for groundwater information. Generally, these records are less complete or at a lower level of temporal and spatial resolution than the data sets required for water management purposes within country.

Code	SDG-6 Global Indicator
6.1.1	Proportion of population using safely managed drinking water services
6.2.1	Proportion of population using safely managed sanitation services, including a handwashing facility with soap and water
6.3.1	Proportion of wastewater safely treated
6.3.2	Proportion of bodies of water with good ambient water quality
6.4.1	Change in water use efficiency over time
6.4.2	Level of water stress: freshwater withdrawal as a proportion of available freshwater resources
6.5.1	Degree of integrated water resources management implementation
6.5.2	Proportion of transboundary basin area with an operational arrangement for water cooperation
6.6.1	Change in the extent of water-related ecosystems over time
6.a.1	Amount of water- and sanitation-related official development assistance that is part of a government coordinated spending plan
6.b.1	Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management

Table 3.2: List of the eleven SDG-6 Global Indicators.

26 https://rsis.ramsar.org/
27 http://www.bafg.de/GRDC/EN/Home/homepage_node.html
28 https://www.un-igrac.org/global-groundwater-information-system-ggis

4
ELEMENTS OF GOOD PRACTICE WATER DATA MANAGEMENT

4.1 INTRODUCTION

When considering what constitutes good practice in managing water data, it is important to give attention to the entire chain of activities between planning data collection through to utilising the data in water information services. This chapter identifies seven elements to good practice in water data management (see Figure 4.1), providing a framework for the guidelines presented in the following chapters.

4.2 WATER MANAGEMENT OBJECTIVES

As noted in the previous chapter, there are a wide range of uses and users for water data. These range from the highly specific and technical requirements of scientists and engineers, to the more general and broad requirements of water policy makers. Resource constraints will always limit how much can be accomplished, so it is important to frame water data management strategies around the priority water management problems that concern stakeholders. Different emphases are required to address the issues of water scarcity, flooding, water quality, agriculture and aquatic ecosystems. Similarly, there is no single water data presentation approach that suits all types of users, so it is also important to prioritise the various audiences for this information.

The success of a water data management strategy will be maximised if framed around the highest priority water management objectives and the specific information needs of stakeholders. These issues will be explored under the chapter entitled *Identify the priority water management objectives*.

4.3 WATER DATA INSTITUTIONS

Having established what kind of water data is needed, it is important to identify who is best equipped to deliver it. In most countries, there are likely to be multiple institutions involved in the collection, distribution, analysis and use of water data. Inevitably, there will be some degree of overlap, gap, competition and synergy amongst the various institutions. In setting a water data management strategy, the roles and responsibilities of each of these institutions should be mapped, discussed, then optimised for the collective benefit of stakeholders. Improving institutional arrangements is possible using a variety of approaches. These range from soft approaches based on collaboration agreements and special program funding, to hard approaches such as machinery of government changes and new legislation. These issues will be explored under the chapter entitled *Strengthen water data institutions*.

Figure 4.1: The seven elements of good practice in water data management

4.4 WATER DATA MONITORING SYSTEMS

As noted in Chapter 3, the diversity of water data types is significant. The monitoring networks required to gather such data are complex too and are likely to be operated by multiple institutions. Substantial ground-based monitoring networks and access to satellite-based data streams are necessary to meet the water data requirements of water managers. Some of the data needed must be gathered continuously or over long time periods to be useful, but this is not the case for all water data. The networks needed to support these varied requirements demand considerable planning, investment, maintenance and on-going modernisation. Water data measurement technology evolves quickly and this provides great opportunities for measuring more and at less cost. However, it also requires flexibility and adaptability in the management of water data monitoring networks. Stable funding arrangements are required not only for the initial capital investment in monitoring networks, but also for on-going maintenance and eventual replacement. These issues will be explored under the chapter entitled *Establish sustainable water data monitoring systems.*

4.5 WATER DATA STANDARDS

The utility value of water data and the trust that users have in it is maximised when the data is collected, curated and shared according to known and accepted data standards. The data format standards used to store and share water data can have a very significant impact on the effort required to utilise it and hence the likelihood of it being used in decision making processes. International standards have emerged in recent years that now make it relatively seamless to store and transmit water data between users and between machines. These issues will be explored under the chapter entitled *Adopt water data standards.*

4.6 WATER DATA ACCESS AND LICENSING

The value of water data is only realised when it is used. Water data is more likely to be used if it is easy to discover, simple to download, and unburdened by restrictive and/or complicated licensing arrangements. Certain countries may have privacy, commercial or national security policies that govern how public and private data is shared. Such policies need to be recognised and possibly modified before establishing water data access and licensing arrangements. However, international experience shows that the more open that water data sharing arrangements are, the more benefit is created. These issues will be explored under the chapter entitled *Embrace an open data approach to water data access and licensing.*

4.7 WATER DATA INFORMATION SYSTEMS

Investments in the collection of water data can be undermined unless sufficient attention is given to the design and operation of water data information systems. These systems are used for many different water data curation tasks and the delivery of water information services to end users. To focus efforts to maximise the effectiveness of water information systems, strategies can be developed to meet particular levels of functionality, maintainability, spatial enablement and dependability. These issues will be explored under the chapter entitled *Implement effective water data information systems.*

4.8 WATER DATA QUALITY MANAGEMENT

Once water data is collected, there is a considerable effort involved in assuring the quality of it and adapting measurement and curation practices to improve its quality over time. Introducing quality management processes into the water data management workflow can have a transformative effect on the quality of water data and the trust that users have in it. These issues will be explored under the chapter entitled *Employ water data quality management processes*.

5 IDENTIFY THE PRIORITY WATER MANAGEMENT OBJECTIVES

5.1 INTRODUCTION

Water data management arrangements will be most successful when designed to enable water stakeholders to address their highest priority water management concerns. Conversely, water data that fails to answer the priority questions being asked will have limited utility value. Hence, the first and most critical step in setting an effective water data management strategy is giving attention to the priority management objectives of water stakeholders.

This can be done by asking a series of questions, such as:

- Which of our many water management problems are the most important to solve?
- What kind of water data is needed to diagnose problems and develop solutions?
- Who will use this water data and what decisions will they need to make?
- What form must the water data be in to be useful in decision making?

5.2 TYPES OF WATER MANAGEMENT OBJECTIVES

Water stakeholders are concerned with a wide range of water management objectives, some of which are highlighted in Table 5.1.

Management objective	Examples of considerations
Reducing flood risk	• Operating early warning systems • Designing effective flood control structures
Providing reliable potable water supply	• Identifying sustainable water sources • Estimating supply and demand fluctuations • Quality of water
Providing effective sanitation services	• Designing effective drainage systems • Selecting appropriate water treatment trains
Designing water supply and drainage infrastructure	• Estimating rainfall Intensity, Frequency, Duration (IFD) relationships • Estimating the Probable Maximum Flood (PMF)
Providing water security for agriculture	• Designing efficient irrigation systems • Setting sustainable limits on water allocation
Providing water security for aquatic ecosystems	• Identifying high value water-dependent ecosystems • Defining environmental flow regimes to sustain ecosystem function
Providing water security for power generation	• Identifying catchments with high reliability water supplies • Dimensioning water storages to operate through protracted drought sequences

Table 5.1: List of common water management objectives and examples of considerations requiring water data.

Most countries will require water data arrangements to suit many of the management objectives listed in Table 5.1. Nonetheless, it will be beneficial to frame any water data management strategy around each objective and to accord each a priority to guide a rational investment strategy.

5.3 KEY ATTRIBUTES OF WATER DATA

Although there will be overlap, the water data requirements for each of the water management objectives outlined in Table 5.1 will be distinctive. Some of the key attributes of water data that will vary across this range of management objectives are outlined in Table 5.2.

Necessary attributes in water data	Examples
Water data parameter type	• River flow data is essential for safe reservoir operations • Water use data is essential for managing irrigation schemes
Water data measurement location	• Groundwater level data is very important for heavily utilised aquifers • Water quality data is very important upstream of water offtakes for communities
Water data spatial coverage	• National scale water assessments require broad data coverage • Flood level data is most critical in flood prone areas, though also vital in contributing catchments
Water data spatial density	• It is beneficial for rainfall networks to be more dense around areas of high rainfall gradients
Water data temporal frequency	• For flood forecasting, continuous high frequency rainfall and river flow data are needed • Daily or even monthly river flow data may be sufficient for assessing regional water security • For estimating sediment and nutrient loads to receiving waters, measurements may be infrequent for low flows but need to be very frequent during high flows
Water data longevity of measurements	• Multi-decadal records of continuous rainfall are necessary for reliable rainfall IFD analysis • Only a few years of data may be needed to calibrate a groundwater model
Water data latency	• Real-time delivery of rainfall and river level data is essential for flood forecasting • Irrigation water use data is not time critical and may be analysed periodically
Water data precision	• Quality of drinking water supplies needs to be measured with high accuracy • High accuracy is not important for estimating soil moisture content in farming lands

Table 5.2: Some of the key attributes of water data that vary according to information needs for various water management objectives.

5.4 CHANGING WATER DATA NEEDS

It is important to note that the various water management objectives outlined in Table 5.1 are never fully met, owing to constant changes in the water supply/demand balance. These changes in the supply/demand balance are stimulated by various forces, such as those outlined in Table 5.3. These changes necessitate on-going evaluation of water data management arrangements to ensure that they continue to meet the priority information needs of water stakeholders.

Force of change	Examples
Climate variability	• Drought sequences become longer and more severe than planned for • Extreme rainfall events become more intense and protracted than planned for
Climate change	• Shifts in weather patterns affect rainfall amount, timing, intensity and reliability • Snow packs and glaciers diminish, changing the timing and volume of flows in rivers • Evaporation rates increase, raising crop water use requirements
Changes in water demand	• Population increases • New settlements are established in areas without developed water resources • Urban water use behavior changes due to pricing, regulatory changes or public attitudes
Changes in catchment landuse	• Type and extent of agricultural enterprises changes • Urbanisation increases stormflow runoff and pollutant loads to receiving waters • New industries are established
Changes in transboundary competition for water access	• Significant water resource development occurs upstream • Significant increase in demand for water downstream • Geopolitical conflict threatens agreed water sharing arrangements

Table 5.3: Some of the forces affecting the water supply/demand balance over time.

Over time, stakeholder priorities may shift too, necessitating a change to the water data management arrangements and their supporting investment profile. International experience shows that the occurrence of unexpected severe weather events such as protracted droughts and massive floods tend to shift government priorities towards new policies to mitigate the impacts of such events in the future. Likewise, major water pollution crises that cause illnesses or death stimulate urgent action to prevent repeat occurrences. Such changes in priority will change the requirements for water data management arrangements too.

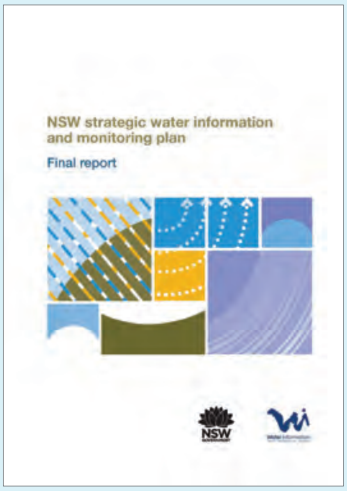
5.5 SUMMARY

In summary, the most effective water data management strategies are framed around priority water management objectives. Establishing the need for specific types of water data to answer particular water management questions will ensure that investments are well targeted. Water data management arrangements should be reviewed periodically as new water management challenges arise and hydrologic conditions change.

5.6 A KEY REFERENCE TO EXAMINE

As part of a number of major water reforms in Australia, the lead water information agency in each State and Territory prepared their own Strategic Water Information and Monitoring Plan. A good example of one of these plans is the *"NSW Strategic Water Information and Monitoring Plan Final Report (December 2009)"*, ISBN 978 1 921546 94 5[29].

This report starts with a comprehensive assessment of New South Wales' most important water management issues and information drivers. These were linked to existing water data assets and used to inform an analysis of gaps in water data and water information systems. The gap analysis later became the foundation for an investment process to improve water information in New South Wales.



29 Available at http://www.water.nsw.gov.au/__data/assets/pdf_file/0008/549674/nsw_swimp_final_report.pdf

6
STRENGTHEN WATER DATA INSTITUTIONS

6.1 INTRODUCTION

Having identified the priority water management objectives and the type of water data needed to address them, attention can next be directed towards the supporting institutional arrangements. In most countries, there are several institutions involved in the collection and management of water data.

In preparing a water data management strategy, it is useful to first map out the roles and responsibilities of each of these institutions. Questions that can be asked are:

- Which institutions are involved in water data collection and management?
- Why are they involved and under what authority?
- What kind of data do they collect and/or manage and from what locations?
- Where are the overlaps, gaps and synergies in their respective activities?

6.2 TYPES OF INSTITUTIONS INVOLVED IN WATER DATA COLLECTION AND MANAGEMENT

Those institutions involved in collecting and managing water data will likely be differentiated in various ways, as set out in Table 6.1. Their authority and motivation for being involved will be governed by their jurisdiction and primary business function. Their mode of operation will be affected by the nature of their business, be it public, private or research. They may undertake either a limited or wide range of water data management activities. The extent of their involvement may be mandated by law or discretionary. In making sense of national water data management arrangements, understanding such differences is important.

6.3 EVALUATING THE SUITABILITY OF INSTITUTIONAL ARRANGEMENTS

Having mapped out the roles, responsibilities and activities of the various institutions involved in water data collection and management, it is then possible to evaluate the suitability of the existing arrangements. Evaluative questions that could be asked include:

- Is there any unnecessary duplication of effort in water data collection, curation, analysis or distribution?
- Are there any critical gaps in effort?
- Does the overall effort meet the requirements of water stakeholders and their priority water management objectives?
- Is cooperation between institutions necessary and is it happening sufficiently?
- Are there efficiencies to be captured by working more closely together and sharing resources?
- Are there any impediments to working more closely together?
- Is water data being shared and is the effort required to obtain it reasonable?
- Do water data users trust the information being made available to them?

There are sound reasons, indeed necessities, for multiple institutions to be involved in water data collection and management. In virtually all cases, each institution will have a specific business requirement for access to water data. However, inevitably there will be some degree of overlap, gap, competition and synergy amongst the various institutions involved in water data, possibly warranting some degree of reform. Mapping out the participants and their activities is the first step in optimising a country's institutional arrangements for water data management.

Differentiating factors	Examples of differences
Jurisdiction of the institution	• National focus • State or Provincial focus • Basin focus • City, Town or Village focus
Primary business function of the institution	• Water policy and regulation • Urban water supply and drainage • Rural water supply and drainage • Basin or regional land and water management • Environmental protection • Environmental water management • Irrigation scheme management • Reservoir and river operations • Flood forecasting and warning • Hydro-electricity generation
Legislative basis of the institution	• Government agency • Government business enterprise • Private water utility • Not for profit NGO • Research institute
Water data management activity of the institution	• Water data monitoring • Water data curation • Water data analysis • Water data dissemination • Water data information services

Table 6.1: Nature of differentiation between the various institutions that may be involved in managing water data.

6.4 IMPROVING INSTITUTIONAL ARRANGEMENTS

If there is a perceived need to improve the institutional arrangements, this is possible using a variety of approaches. Some example approaches are set out in Table 6.2, including collaborative agreements, special program funding, legislative change and machinery of government changes.

The most appropriate approach to reforming water data institutional arrangements will depend on:

- How urgent, critical or complex the task of reform is
- The availability of financial resources to support the reform process
- The preferences of the key water data stakeholders
- The level of political and administrative support for change

Some countries will be beset by significant gaps in water data and supporting technical infrastructure, a shortage of funding and a lack of technical capacity. In such situations, there will be a greater imperative to undertake major reform of the existing institutional arrangements or to establish entirely new structures that can operate efficiently and effectively with limited resources.

Approach	Comments
Collaborative agreements *Parties formalize their working relationship in a written agreement setting out their respective roles and responsibilities and their commitment to assist one another*	• Relatively informal and easy to implement • Relies on goodwill of participants • May or may not have 'enforceable' obligations • Less likely to yield substantive change
Special program funding *Funding programs are offered to address water data gaps, improve institutional capacity and incentivize improved cooperation*	• If resources are available, relatively easy to implement • Allows new activities to be undertaken or to improve existing activities • Participants more likely to change their behaviour if funded to do so • Depending on nature of investment, benefits may diminish after cessation of special funding
Legislative change *Laws are enacted to mandate new water data responsibilities for one or more institutions or to establish new bodies*	• Removes ambiguity and establishes a clear mandate • Gives authority to institution • Can be used to mandate specific behaviours such as free and open sharing of water data • May require allocation of dedicated resources to be effective
Machinery of government change *Government directs the transfer of functions from one agency to another, the merging of agencies or the formation of new agencies*	• Removes ambiguity and establishes a clear mandate • May be disruptive in the short term • May yield efficiencies in the long term • Requires political and administrative support

Table 6.2: Different approaches to improving institutional arrangements for water data management.

6.5 SUCCESS FACTORS FOR WATER DATA MANAGEMENT INSTITUTIONS

In shaping or building new water data institutions, it is useful to focus on the factors that are required for success in water data management. Some of these success factors are described in Table 6.3. These various factors have technical, cultural, logistical and reputational dimensions. Any program to reform national institutional arrangements for managing water data is more likely to be effective if it is planned around enhancing these success factors.

Factors of success	Comments
Domain knowledge	It is difficult to manage water data effectively unless those responsible for the collection and curation of it have a good understanding of the provenance, fidelity and use of the data. It is more likely that water data will be expertly curated and utilized if managed by people with solid water science and engineering knowledge.
Technical infrastructure	It is beneficial to assign complex water data management roles to agencies with competencies in operating specialized IT infrastructure such as communication networks, data warehouses, Geographic Information Systems, hydrologic models and web sites.
Aligned expertise	Much water data has a close affinity to other types of environmental information such as weather, climate, hydrogeology and ecologic data. Assigning certain water data management responsibilities to agencies with complementary subject matter expertise may yield efficiencies.
Operational experience	Certain water data tasks that require high levels of service reliability and quality are best assigned to agencies with strong operational experience, underpinned by cultures of quality management.
Critical mass	Having too few staff involved in any water data management task stymies career development for water data professionals and reduces organizational resilience. Hence, it is beneficial to group highly specialized staff into larger teams.
Independence	When water resources are strongly contested between different users it may be of benefit to have certain water data functions managed by an agency independent of any water policy, water management or water regulatory function.

Table 6.3: Some of the success factors for water data management institutions.

6.6 IMPLEMENTING INSTITUTIONAL REFORMS

Once a commitment to reform in institutional arrangements is made, it is important to plan and execute the change process carefully. Some of the most important considerations are:

- Consulting with stakeholders to establish the value proposition for change
- Ensuring that subject matter experts are involved in designing the new arrangements
- Documenting and communicating the key steps in the change process
- Specifying the expected benefits and monitoring their realisation over time
- Assessing and mitigating all risks associated with the changes
- Allocating the necessary financial and human resources to the change process
- Securing the trust and support of key stakeholders by explaining the merits of the proposed changes, addressing their concerns and keeping them informed throughout the change process

6.7 SUMMARY

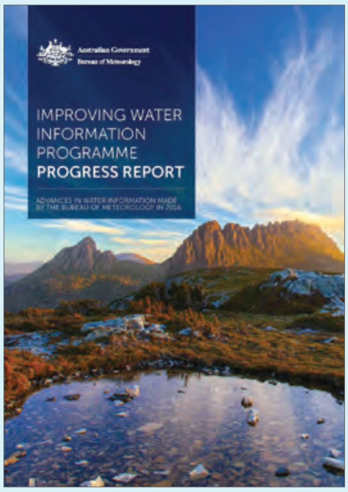
In summary, it is valuable to map out the roles, responsibilities, activities and water data holdings of all institutions involved in water data management. Having done that it is then possible to evaluate the suitability of the existing arrangements and explore options for improving them. Reforming institutional arrangements can be undertaken using a variety of 'soft' and 'hard' approaches. It is beneficial for reforms to be guided by a carefully designed change management process, underpinned by a clear articulation of the benefits being sought.

6.8 A KEY REFERENCE TO EXAMINE

As part of a series of major water reforms in Australia in 2007, the Bureau of Meteorology was assigned the role as the national water information authority[30].

The Bureau was accorded legal powers under the *Water Act 2007*[31], including the power to collect water data from over 180 data collecting agencies as set out in the *Water Regulations 2008*[32]. The Bureau was required to freely share the data it collected, as well as derived water information services.

The background to and benefits of the Improving Water Information Program are summarised in the Program's 2016 Progress Report[33], available at the Bureau of Meteorology web site.



30 See http://pandora.nla.gov.au/pan/10052/200703210000/www.pm.gov.au/docs/national_plan_water_security.pdf
31 See Part 7 of the Water Act 2007 at https://www.legislation.gov.au/Details/C2016C00469
32 See Part 7 of the Water Regulations 2008 at https://www.legislation.gov.au/Details/F2017C00250
33 See http://www.bom.gov.au/water/about/publications/document/progress_report2016.pdf

7
ESTABLISH SUSTAINABLE WATER DATA MONITORING SYSTEMS

7.1 INTRODUCTION

The essential foundation of any water data management strategy is the water data monitoring system, as this is the source of the primary data upon which all subsequent analyses, reports and forecasts depend.

In Chapter 3 we noted that there were four basic sources of water data, these being direct measurements, inference from remote sensing, administrative data collection and estimation from models. The first two of these may be considered two distinct elements of a water data monitoring system, both relying on measurement by instruments. Direct measurements require the operation of ground-based measurement instrumentation, whereas inference from remote sensing entails analysis of satellite or other imagery. Satellite imagery is usually collected by space agencies and then shared with users, either freely or under commercial licensing arrangements.

There are three basic considerations in establishing a water data monitoring system. These are:

1. Identifying the user requirements for the monitoring system
2. Specifying the operating requirements for the monitoring system
3. Implementing a sustainable funding regime for the monitoring system

Water data monitoring systems must be thought of as a long-term investment that yield most benefits when they are carefully planned, diligently operated and securely funded. In this chapter, guidance is provided on how to create fit for purpose monitoring systems and how to sustain them.

7.2 IDENTIFYING THE USER REQUIREMENTS FOR THE MONITORING SYSTEM

In Chapter 5 we stressed the importance of defining the priority water management objectives. Having done that, it is possible to specify what water data will be needed to address those objectives and then to design the monitoring system that can supply that data. Forging a strong link between the water management objectives and the supporting water data monitoring system will help to ensure that investments in water data collection are well targeted. It will also help to ensure that the key questions relating to each priority water management objective can be answered.

A good way to approach the user requirements analysis is to ask a series of questions from the point of view of the water data user. Such questions should be asked in relation to each of the priority water data management objectives previously articulated. Some of the questions that can be asked in this process include:

- What water data parameters need to be measured?
- Where must the measurements be taken?
- How regularly must the measurements be made?
- What level of measurement accuracy is required?
- What is the required operating uptime of the monitoring system? Is it tolerable to have occasional data gaps or must the monitoring record be continuous?
- What is the required data latency? Is there a need to obtain the data in real time, on a regular schedule, or periodically?
- What is the required period of monitoring? Is it short-term or on-going?
- What format must the water data be in to meet the user's needs?
- What information system(s) will the water data be stored in?
- What supporting metadata is required for users of the water data to properly interpret it?

7.3 SPECIFYING THE OPERATING REQUIREMENTS FOR THE MONITORING SYSTEM

Once the user requirements are understood, the next task is to determine how best to supply the required water data. For any water data parameter to be collected there will be a need to specify exactly how the measurements should be made. This will include the choice of measurement instrument and associated communications systems, as well as its siting, installation, calibration, operation and servicing. In the case of remote sensing information, the considerations will be different, relating to the choice of satellite imagery and the post-processing algorithms that render the imagery fit for particular uses.

A good way to start the process of specifying the monitoring system operating requirements is to ask a series of questions from the point of view of the technical staff who must install, operate and maintain the monitoring system. Some of the questions that can be asked in this process include:

- What are the preferred methods of measurement for each water data parameter of interest?
- What are the siting requirements and access arrangements for each monitoring location?
- What are the necessary site and equipment registration details and where should that information be stored?
- What are the calibration requirements for the measurement instrumentation?
- What kind of communication system is required to relay the monitoring data from the field?
- What if any level of redundancy is required for the measurement instrumentation and the associated communications systems?
- What are the servicing requirements for the site and the measurement instrumentation?
- What are the power requirements for the monitoring system?
- What measures are needed to protect the measurement equipment need from extreme weather conditions, theft and vandalism?
- What is the expected operating life of the monitoring equipment?

The capability, reliability and economics of water data measurement technology are continually improving, so it is important to keep abreast of new developments and seize opportunities when they are presented. However, it is generally unwise to adopt 'bleeding edge' technology and it is better to wait until the new measurement methods have undergone robust field testing and system integration by others.

7.4 IMPLEMENTING A SECURE FUNDING REGIME FOR THE MONITORING SYSTEM

The costs of establishing and maintaining a water data monitoring system can be substantial, so diligent, long-range financial management is vital. The main costs involved span the following categories of capital and operating expenditure:

- Capital funds for the initial acquisition and installation of monitoring equipment
- Capital funds for the repair and replacement of monitoring equipment
- Operating funds for the periodic servicing of monitoring sites and periodic calibration of measurement instruments
- Operating funds for the telecommunications charges for water data transmission from the field to the office
- Operating funds for the recurrent licensing fees for necessary supporting software
- Operating funds for the recurrent licensing fees for necessary remote sensing imagery and associated post-processing services
- Operating funds for the associated water data curation processes such as quality control
- Operating funds for the on-going training of technical staff engaged in water data monitoring
- Operating funds for the periodic review of water data monitoring arrangements and associated water data curation processes

One of the more common mistakes made in a water data management strategy is the failure to make a secure, on-going provision for this full list of funding requirements. Many water data collecting agencies have benefited from generous "one-off" grants to establish water data monitoring networks, only to see them quickly degraded due to lack of resources for maintenance and eventual replacement. Another common mistake precipitated by poor funding arrangements is the failure to secure resources to properly calibrate measurement equipment and remote sensing algorithms. Failing to calibrate equipment and algorithms renders collected water data of limited use because of uncertain accuracy.

As was noted earlier, water data measurement technology and procedures are constantly changing, so there is an on-going need to invest in the training of technical staff involved in water data monitoring. This also improves the ability of staff to provide the water data collecting agency with sound advice on different aspects of water data monitoring.

7.5 WHO SHOULD PAY FOR WATER DATA?

It has been noted that the costs of water data collection, curation, interpretation and sharing can be substantial. However, it has also been noted that the value of water data is very high, presenting a good return on investment for governments that choose to invest in it. Despite this, many countries, and developing nations in particular, struggle to allocate sufficient funding to water data.

This begs the question, who should pay for water data? The de-facto funder of water data services has always been the State, in its role as a provider of public goods that markets fail to provide efficiently. Governments confronted by budgetary pressures continuously seek to defray their costs of operation and water data services are one of the many activities of the State that attracts the attention of budget managers. However, because of the intrinsic value of water data services in promoting economic efficiency, environmental sustainability and public safety, most governments have reasoned that it is counterproductive to divest entirely from water data services. Instead, some governments have sought ways to transfer the cost burden of water data services to others, at least in part. In doing so, governments have generally adopted one of two approaches.

The first of these is to charge users of water data services an access fee. This approach runs counter to the modern-day ethos of 'open data', discussed in Chapter 9 of these guidelines. Unsurprisingly, most attempts to monetise water data have been unsuccessful for several reasons. Though the utility value of water data is high, the number of uses for it is relatively small compared to most commercial goods, and dominated by public sector users anyway. This makes it very difficult to monetise water data and so the cost of managing access is usually greater than the return from access fees. In addition, experience indicates that imposing an access fee discourages utilisation of water data, which reduces the benefit that can be derived from it.

The second and far more successful approach is to pass on the cost of water data services to water consumers via water usage charges. Under this approach it is reasoned that water data service costs are a legitimate part of the overall cost of delivering water to consumers. These costs are reflected in water use charges in the same way that the costs of dams, pipes, treatment facilities and administration are included, at least partially. The attractions of this approach are that the funding base is very broad, the impost on individual water consumers is very small and that an appropriate cost levying process is already in place. Another important attraction of this approach is that the return on investment in water data services is positive, so water consumers benefit by contributing towards the cost of them.

A good example of this approach in action is reflected in the practice adopted by the New South Wales (NSW) state government in Australia. In NSW, the State water delivery agency applied to the Independent Pricing and Regulatory Tribunal of NSW (IPART NSW) to internalise part of the cost of water data services into the water usage charge levied on consumers. IPART NSW is responsible for setting maximum service charges for cost recovery of public services provided by the State government. It makes determinations based on consultations with service providers and consumers. Table 7.1 summarises the agreed cost recovery limits on the full list of water management activities undertaken by the NSW state government, around half of which could be characterised as water data services. The list includes a comprehensive suite of monitoring, modelling and reporting activities that enable the State to provide water security for the public.

7 ESTABLISH SUSTAINABLE WATER DATA MONITORING SYSTEMS

Activity code	Activity description	User share of costs %
W01	**Surface water monitoring**	
W01-01	Surface water quantity monitoring	70%
W01-02	Surface water data management & reporting	50%
W01-03	Surface water quality monitoring	50%
W01-04	Surface water algal monitoring	50%
W01-05	Surface water ecological condition monitoring	50%
W02	**Groundwater monitoring**	
W02-01	Groundwater quantity monitoring	100%
W02-02	Groundwater quality monitoring	100%
W02-03	Groundwater data management & reporting	100%
W03	**Water take monitoring**	
W03-01	Water take data collection	Fee for service
W03-02	Metering data management & reporting	100%
W04	**Water modelling and impact assessment**	
W04-01	Surface water modelling	50%
W04-02	Groundwater modelling	100%
W04-03	Water resource accounting	100%
W05	**Water management implementation**	
W05-01	Systems operation and water availability management	100%
W05-02	Blue-green algae management	50%
W05-03	Environmental water management	0%
W05-04	Water plan performance monitoring and evaluation	50%
W06	**Water management planning**	
W06-01	Water plan development (coastal)	70%
W06-02	Water plan development (inland)	70%
W06-03	Floodplain management plan development	0%
W06-04	Drainage management plan development	0%
W06-05	Regional planning and management strategies	70%
W06-06	Development of water planning and regulatory framework	75%
W06-07	Cross-border and national commitments	50%
W07	**Water management works**	
W07-01	Water management works	50%
W08	**Water regulation management**	
W08-01	Regulation systems management	100%
W08-02	Consents management and licence conversion	100%

Activity code	Activity description	User share of costs %
W08-03	Compliance management	100%
W08-99	Water consents overheads	100%
W09	**Water consents transactions**	
W09-01	Water consents transactions	100%
W10	**Business and customer service administration**	
W10-01	Customer management	100%
W10-02	Business governance and support	70%
W10-03	Billing management	100%

Table 7.1. List of water management activities provided by the NSW state government, indicating the percentage of costs allowed to be recovered from water consumers via levied water usage charges.[34]

7.6 SUMMARY

In summary, sustainable water data monitoring systems have some key characteristics. First, they are designed to generate data at the appropriate level of geographic coverage, temporal and spatial scale and precision to answer questions related to priority water management objectives. Second, they are founded on clearly specified and achievable operating requirements, accepted by those charged with the responsibility to install, operate, maintain and replace the measurement instrumentation and associated communication systems. Third, they are underpinned by appropriate and secure funding regimes covering initial installation, on-going maintenance and replacement of equipment, as well as the associated costs of periodic calibration and water data curation processes. This entails access to recurrent operating and capital funding streams that are reasonably secure and subject to periodic review.

34 From http://www.water.nsw.gov.au/water-management/fees-and-charges/price-setting

7.7 A KEY REFERENCE TO EXAMINE

There are several excellent texts available that provide guidance on how to go about designing and operating water data monitoring networks. One of the more authoritative and comprehensive is World Meteorological Organization (WMO) Publication No. 168, entitled *"Guide to Hydrological Practices, Volume 1: Hydrology – From Measurement to Hydrological Information"* (Sixth Edition, 2008), ISBN 978-92-63-10168-6[35].

This manual deals with methods of observation for precipitation, evapotranspiration, surface water, groundwater, water quality and aquatic ecosystems. It also covers matters of data processing and quality control, safety in the field and data storage, access and sharing.

35 Available at http://www.whycos.org/chy/guide/168_Vol_I_en.pdf

8 ADOPT WATER DATA STANDARDS

8.1 INTRODUCTION

The utility value of water data, and the efficiency in handling it, are greatly enhanced by the adoption of water data standards. Standards engender trust in water data and yield considerable productivity benefits for both the suppliers and users of water data. As the details for most water data standards are freely available in the public domain, there are few barriers to adopting them other than a commitment to the necessary resourcing and staff training.

There are two broad areas of water data standards that will be covered in this chapter, namely standards for the acquisition of water data, and standards for the transfer of water data.

8.2 STANDARDS FOR THE ACQUISITION OF WATER DATA

Standards for the acquisition of water data encompass methods of field observation and methods of laboratory analysis of water samples. Field observation procedures include those for measuring precipitation, river discharges, groundwater levels and a variety of water quality parameters. In the case of water quality data, there are also standard methods for analysis of samples in the laboratory. A selective sample of some of the most prominent field observation and laboratory analysis standards is listed in Table 8.1.

Standard	Comments
Guide to Meteorological Instruments and Methods of Observation. Authors: World Meteorological Organization (WMO) Publication No. 8 (2008).[36]	This document is the most definitive guide for measuring meteorological variables, some of which are also key water data parameters. It is published by the World Meteorological Organization and adopted by most of the world's National Hydrological and Meteorological Services.
Guide to Hydrological Practices, Volume 1: Hydrology – From Measurement to Hydrological Information. Authors: World Meteorological Organization (WMO) Publication No. 168 (2008).[37]	This document is the most definitive guide for measuring hydrological variables. It is published by the World Meteorological Organization and adopted by many of the world's National Hydrological and Meteorological Services. It includes chapters on the measurement of precipitation, evaporation, soil moisture, streamflow, groundwater, sediment, water quality and ecosystem attributes. It also includes chapters dedicated to data processing, quality control, data storage, access and sharing.
Discharge measurements at gaging stations. Authors: Turnipseed, D.P., and Sauer, V.B. (2010) U.S. Geological Survey Techniques and Methods Book 3, Chapter A8.[38]	This document is the most authoritative guide for measuring discharge in rivers. It constitutes the standard operating procedure for hydrometric measurements by the United States Geological Survey but has also been adopted widely around the world. It also has been used as the foundation for many other standards related to discharge measurement.

Standard	Comments
Groundwater technical procedures of the U.S. Geological Survey. Authors: Cunningham, W.L., and Schalk, C.W. (2001) U.S. Geological Survey Techniques and Methods 1–A1.[39]	This document contains a compilation of technical procedures used by the United States Geological Survey for the measurement of groundwater levels. The procedures outlined have been adopted widely around the world.
Guidelines and standard procedures for continuous water-quality monitors—Station operation, record computation, and data reporting. Authors: Wagner, R.J., Boulger, R.W., Jr., Oblinger, C.J., and Smith, B.A. (2006) U.S. Geological Survey Techniques and Methods 1–D3.[40]	This document contains a compilation of technical procedures used by the United States Geological Survey for the continuous monitoring of a variety of water quality variables such as water temperature, salinity, pH, dissolved oxygen and turbidity. The procedures outlined have been adopted widely around the world.
Physical, chemical and biochemical methods for water quality analysis. Authors: International Organization for Standardization (ISO) ISO/TC 147/SC2.[41]	This standards catalogue contains over 100 standards for the analysis of various water quality parameters. ISO standards, in general, are regarded as definitive international standards.
Standard Methods for the Examination of Water and Wastewater. Authors: E.W. Rice, R.B. Baird, A.D. Eaton, L.S. Clesceri, eds. (2012) American Public Health Association, American Water Works Association and the Water Environment Federation.[42]	This standards catalogue contains over 400 standards for the analysis of various water and wastewater quality parameters. It is regarded as the definitive American standard for water and waste water analysis and is used widely around the world.
Australian Guidelines for Water Quality Monitoring and Reporting. Authors: Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (2000).[43]	This document constitutes the Australian and New Zealand national standard for water quality monitoring and reporting. It contains a compilation of technical procedures for the collection of water samples, as well as their analysis, interpretation and reporting.

Table 8.1: Selected standards for the acquisition of water data, relating to methods of field observation and laboratory analysis of water samples.

36 Available free online at https://www.wmo.int/pages/prog/gcos/documents/gruanmanuals/CIMO/CIMO_Guide-7th_Edition-2008.pdf
37 Available free online at http://www.whycos.org/chy/guide/168_Vol_I_en.pdf
38 Available free online at https://pubs.usgs.gov/tm/tm3-a8/
39 Available free online at https://pubs.usgs.gov/tm/1a1/
40 Available free online at http://pubs.water.usgs.gov/tm1d3
41 Available commercially online at https://www.iso.org/committee/52846/x/catalogue/
42 Available commercially online at http://www.standardmethods.org/
43 Available free online at http://www.agriculture.gov.au/SiteCollectionDocuments/water/nwqms-monitoring-reporting.pdf

The examples listed in Table 8.1 have been published by various national and international bodies, including the World Meteorological Organization (WMO), the United States Geological Survey (USGS), the International Organization for Standardization (ISO), the American Public Health Association (APHA) and the Australian and New Zealand Environment and Conservation Council (ANZECC). It should be noted that several acceptable alternatives to these standards have been published by other bodies from around the world, but that those profiled here are amongst the more highly regarded and are therefore recommended for consideration.

It is recommended that prior to adopting any of the standards listed in Table 8.1, or alternatives, that a review is undertaken of existing and planned water data collection activities to identify which tasks are candidates for the application of standards. With a clear view of where standards might apply, it would then be beneficial to undertake a study tour of relevant water data agencies to examine their approaches to integrating standards into their water data collection and analysis work flows. Obtaining advice from peers on how standards are selected and applied in their real-world circumstances will reveal watch points and potential valuable short cuts that can help smooth and accelerate implementation

8.3 STANDARDS FOR THE TRANSFER OF WATER DATA

Although water data is normally collected by an agency for a very specific purpose, there is almost always a need to share it more widely with others. This need is not confined to a country as some 90% of people live in countries that share transboundary hydrological features.[44] Hence there is a need to share water data locally, regionally, nationally and internationally. For this to happen seamlessly it is necessary to have water data transfer standards. Water data transfer standards may be thought of as the rules by which water data are described, enabling them to be shared, exchanged, and understood.

44 See UN-Water (2008) Transboundary Waters: Sharing benefits, Sharing Responsibilities, available online at http://www.unwater.org/downloads/UNW_TRANSBOUNDARY.pdf

One of the bigger barriers to transferring water data has been the huge variety of non-standard formats used for describing and storing it. This has made it extremely difficult to exchange water data, resulting in confusion, delays, errors and costs whenever data is transmitted from owners to users, exchanged between information systems, or whenever water information systems are upgraded.

It is only in the last few years that robust international water data transfer standards have emerged to remedy this situation. Machine-readable water data exchange standards are now available that make it relatively seamless to exchange water data between different systems and users.

The definitive international standard for describing, storing and transmitting water data is a group of standards known as WaterML2.0, published by the Open Geospatial Consortium (OGC).[45] OGC are the pre-eminent standards setting body for many kinds of environmental data. The WaterML2.0 standard was developed by the Hydrology Domain Working Group[46], operating under the auspices of the OGC and the WMO, and involving technical experts from several countries.

WaterML2.0 is a five-part standard comprised of discrete information models for the exchange of hydrologic time series information, streamflow ratings, surface hydrology features, groundwater data and water quality data (see Table 8.2). The basis of these standards is a series of eXtensible Markup Language (XML) schemas. XML is a software- and hardware-independent tool for storing and transporting data, much like the HTML language standard that is used to display data on web pages.

The WaterML2.0 standard describes not only the format of the data, but its meaning. This is possible because the standard allows for the attachment and carriage of detailed metadata concerning the water data, such as the type, location, time, method and quality of the measurement. The ability to carry this ancillary information with the data means that any person or machine wishing to access the water data can understand its utility and limitations.

45 See http://www.opengeospatial.org/standards/waterml
46 See http://www.opengeospatial.org/projects/groups/hydrologydwg

To date, three parts of WaterML2.0 have been formally endorsed by the OGC, with the remaining two parts developed but still pending formal approval. In the first instance, it is recommended that Parts 1, 2 and 4 are adopted and a watching brief maintained on the evolution of the other two parts of WaterML2.0. It is expected that these will mature into formally endorsed standards over the next 1-2 years.

Many leading water data agencies have already adopted Parts 1 and 2 of the WaterML2.0 standard and support is provided by the two leading vendors of water information systems, Kisters[47] and Aquatic Informatics[48]. The rigour of the OGC standards setting process, the high degree of stakeholder consultation involved and its wide adoption will ensure that the WaterML2.0 standard will persist as the dominant international water transfer standard for some time to come.

47 See http://www.kisters.eu/
48 See http://aquaticinformatics.com/

Part	Description	Status @ November 2017
WaterML2.0 Part1: Time Series Encoding Standard	A standard information model for exchanging water observations data sets between users and information systems. Highly recommended for adoption.	Endorsed and published by OGC[49]
WaterML2.0 Part2: Ratings, Gaugings and Sections	A standard information model for exchanging rating tables, gauging observations, and river sections. Highly recommended for adoption.	Endorsed and published by OGC[50]
WaterML2.0 Part3: Surface Hydrology Features	A standard information model for defining fundamental relationships among major components of the hydrosphere such as hierarchies of catchments, river network topologies and water bodies. Further reference to this standard will be made in Chapter 10 of these guidelines. Highly recommended for adoption once approved.	Being considered by OGC for endorsement[51]
WaterML2.0 Part4: Groundwater	A standard information model for the exchange of groundwater data, also referred to as GroundWaterML2.0 (GWML2). Highly recommended for adoption.	Endorsed and published by OGC[52]
WaterML2.0 Part5: Water Quality	A standard information model for the exchange of water quality data. Still in early stages of development and consultation amongst the water data community.	Being considered by OGC for endorsement[53]

Table 8.2: Components of the WaterML2.0 water data exchange standard.

49 See https://portal.opengeospatial.org/files/?artifact_id=57222
50 See http://docs.opengeospatial.org/is/15-018r2/15-018r2.html
51 See https://portal.opengeospatial.org/files/?artifact_id=72353&version=3
52 See http://docs.opengeospatial.org/is/16-032r2/16-032r2.html
53 See http://docs.opengeospatial.org/bp/14-003/14-003.html

8.4 SUMMARY

In summary, the utility value of water data is greatly enhanced by the adoption of water data standards and quality management processes. Water data standards include (1) standards guiding methods of field observation and the laboratory analysis of water samples, and (2) standards for storing and transmitting water data. Many different standards exist for field observations and water sample analyses, though it is recommended that the more popular international and national standards are considered. The definitive water data transfer standard is WaterML2.0, published by the OGC. This standard is relatively new and is continuing to develop. This demands an on-going watching brief on the evolution of the standard and an adaptive approach to its adoption.

8.5 A KEY REFERENCE TO EXAMINE


Open Geospatial Consortium

OGC Information Technology Standards for Sustainable Development

Copyright notice

Copyright © 2015 Open Geospatial Consortium

Warning

The Open Geospatial Consortium (OGC) is an international industry consortium of over 521 companies, government agencies and universities participating in a consensus process to develop publicly available interface standards. OGC has played a significant role in the development of standards for the exchange of environmental information. Of particular relevance is the WaterML2.0 exchange standard for water data.

This document, entitled *"OGC Information Standards for Sustainable Development"*[54], overviews OGC activity across environmental information standards, putting its efforts in water data into a broader context directed at sustainable development.

54 Available free online at https://portal.opengeospatial.org/files/?artifact_id=60920

9 EMBRACE AN OPEN DATA APPROACH TO WATER DATA ACCESS AND LICENSING

9.1 INTRODUCTION

As was noted earlier in these guidelines, most water data are collected for a specific purpose, though the overall utility value of this data is almost always far greater. In the previous chapter, we discussed how water data transfer standards are a key enabler of data sharing. However, transfer formats alone will not enable sharing of water data because it is also critical to implement water data access arrangements underpinned by supportive data licensing regimes.

9.2 WHAT IS OPEN DATA?

Open data is defined as *"data that can be freely used, re-used and redistributed by anyone, subject only, at most, to the requirement to attribute and sharealike"*.[55] International experience shows that the more "open" that data is, the more economic and social benefit is created. It is therefore recommended that an open data approach is considered when establishing access arrangements for water data.

Numerous studies have identified the multiple benefits of adopting an open data approach to government data in general. Analyses published by Lateral Economics (2014)[56] and the European Union (EU)[57] assert that the potential economic value that could be unlocked by adopting open data policies across all activity areas of government is massive.

55 See http://opendatahandbook.org/guide/en/what-is-open-data/

56 See Lateral Economics (2014) Open for Business: How Open Data Can Help Achieve the G20 Growth Target, available free online at http://www.omidyar.com/sites/default/files/file_archive/insights/ON%20Report_061114_FNL.pdf

57 See https://www.europeandataportal.eu/sites/default/files/edp_creating_value_through_open_data_0.pdf

Some of the many benefits expected to flow from open data policies in government include[58]:

- Improving the efficiency of public services
- Improving data quality
- Developing innovative services;
- Creating new business models
- Improving transparency and accountability
- Enhancing citizen participation

The decision to make data freely available and readily accessible to everyone is a fundamental matter of policy for the data owner, which is usually government. Certain countries may have privacy, commercial or national security policies that govern how public and private data is shared. Such policies need to be recognised before establishing water data access and licensing arrangements. However, insofar as there is latitude to declare water data as "open", it is strongly recommended to do so.

There are several compelling reasons to make the open data approach the de-facto standard for water data. The first of these is that maximising the utilisation of water data increases the public benefit, by promoting more efficient and sustainable use of the resource and increased public safety. The second is that transparency engenders trust amongst water stakeholders, providing an evidence base for related public policy. This is particularly important in the case of a highly contested resource such as water, where there are inevitably difficult compromises to be made between those competing for access to it. If the open data approach is the de-facto standard for water data it follows that the burden of proof be placed on those arguing for restricted access, be it for commercial, privacy or national security considerations.

58 See https://www.europeandataportal.eu/en/using-data/benefits-of-open-data

Characteristics of Open Data	Meaning
Freely available to download	• There is no cost to access the data. • Access is via an internet accessible download. • Data is in a form that can be readily downloaded.
Licensed	• An open license is applied.
Well described	• Standards based metadata is used with details of data elements and inclusion of data dictionaries. • Describe the purpose of the collection, the characteristics of the sample and the method of data collection.
Provided in an open format	• The data is in a convenient, modifiable and open format that can be readily retrieved, downloaded, indexed and searched. • Where possible, formats should be machine-readable and non-proprietary formats are preferred.
Well managed	• The data is managed on an ongoing basis with a point of contact designated to assist with data use.

Table 9.1: The five characteristics of open data, adapted from Australian National Data Service (ANDS).[59]

Various resources exist on the internet to assist agencies with their planning around implementation of open data policies. One very useful and freely available resource is the Open Data Readiness Assessment (ODRA) Tool, developed by the World Bank.[60] This rapid diagnostic tool can be applied at the national, state, municipal or individual agency level. It gives attention to eight diagnostic criteria, including leadership, the policy and legal framework, institutional structures and responsibilities, data management policies and procedures, the demand for open data, civic engagement, funding arrangements and the available technology and skills infrastructure.

59 See http://www.ands.org.au/working-with-data/articulating-the-value-of-open-data/open-data

60 Available free online at http://opendatatoolkit.worldbank.org/en/odra.html

MAKING WATER DATA OPEN

So, what is involved in making *water data* "open"? One way to answer this question is to give attention to the characteristics of open data and to explore what is involved in realising those characteristics in the special case of water data. The Australian National Data Service (ANDS) have identified five main characteristics of open data.[61] These are set out in Table 9.1 and discussed below.

61 See http://www.ands.org.au/working-with-data/articulating-the-value-of-open-data/open-data

9 EMBRACE AN OPEN DATA APPROACH TO WATER DATA ACCESS AND LICENSING

Making water data freely available and readily accessible requires the data to be stored in a secure online repository that supports significant data download volumes. An ideal IT solution for this application is a data warehouse[62], associated with a managed cloud service.[63] The benefits of such an approach are reliability, security, scalability and cost efficiency. Such technologies can be managed in-house but require specialist skills and IT resources. Countries lacking access to advanced IT skills and infrastructure can therefore still make progress via purchasing managed services.

To make the data discoverable, the water data needs to be assigned a logically constructed, machine-readable address and listed in a catalogue that is searchable online. A good example of a water data catalogue is provided by the Consortium of Universities for the Advancement of Hydrological Science Inc. (CUAHSI), referred to as the *CUAHSI HIS HydroClient*.[64]

In addition to being able to find the data, there is a need for the data to be readily interpreted. This requires that data is stored in a standard format, with appropriate metadata attached, so that it can be interpreted by users and machines requiring access to it. As noted in the previous chapter of these guidelines, the WaterML2.0 water data transfer standard[65] is ideal for this purpose. This is a robust, open standard that helps seamless transfer between users, machines and modules of water information systems.

To aid efficient discovery, querying and downloading of water data, a map-based web application is required as the 'human interface'. Some of the key functions of such an application are as follows:

- Show location of all water data points available on a zoom-able map
- Filter data shown according to data type and geographic location
- Show list of monitoring station names and numbers available
- Show start and end dates of records and any intervening gaps
- Show data quality codes for all water data available
- Plot water data values as a time series when selected
- Query individual water data values in the plotted time series
- Aggregate water data values to daily, weekly, monthly or annual means or totals
- Download full or partial data series when selected

Many such applications exist on the internet and a good example is provided by the Australian Bureau of Meteorology at *Water Data Online*.[66]

9.3 APPLYING AN OPEN DATA LICENSE

Restrictive data licensing has been a significant impediment to the use of water data, so an open data licensing approach is recommended. There are many good sources of information on open licensing available online.[67,68,69] Two of the most widely used open data license groups in the water data community are the *Open Data Commons*[70] and the *Creative Commons*[71]. Both of these license groups share some common features, including:

- They are based on copyright law and protect the rights of data owners
- They contain strong limitation of liability and warranty clauses
- They provide access to free licenses and tools
- They allow users to share, reuse and remix copyright material in a legal and standardised way
- They are widely used in the open data movement
- They cater for a variety of use cases by providing several variants of the license
- They are internet friendly
- They are free and cost little or nothing to implement

An open license is not necessarily free of limitations. Data owners may wish to place certain levels of restriction on the use of the water data that they are licensing, so the capacity to tailor the open license is important. Some open licenses therefore permit variations to cater for different user needs. As an example, there are six license variations catered for under the Creative Commons license group. These variations are summarised in Table 9.2.

62 See http://www.gartner.com/it-glossary/data-warehouse/
63 See http://www.gartner.com/it-glossary/cloud-management-platforms/
64 See http://data.cuahsi.org/
65 See http://www.opengeospatial.org/standards/waterml
66 See http://www.bom.gov.au/waterdata/
67 See http://discovery.ac.uk/files/pdf/Licensing_Open_Data_A_Practical_Guide.pdf
68 See http://opendefinition.org/licenses/
69 See https://project-open-data.cio.gov/open-licenses/
70 See https://opendatacommons.org/
71 See https://creativecommons.org/

Creative Commons License Name	Features[72]
Attribution License code: (CC BY)	This license lets others distribute, remix, tweak, and build upon the owner's work, even commercially, as long as they credit the owner for the original creation. This is the most accommodating of licenses offered and is recommended for maximum dissemination and use of licensed materials.
Attribution-ShareAlike License code: (CC BY-SA)	This license lets others remix, tweak, and build upon the owner's work even for commercial purposes, as long as they credit the owner and license their new creations under the identical terms. All new works based on the owner's will carry the same license, so any derivatives will also allow commercial use.
Attribution-NoDerivatives License code: (CC BY-ND)	This license allows for redistribution, commercial and non-commercial, as long as it is passed along unchanged and in whole, with credit to the owner.
Attribution-NonCommercial License code: (CC BY-NC)	This license lets others remix, tweak, and build upon the owner's work non-commercially, and although their new works must also acknowledge the owner and be non-commercial, they don't have to license their derivative works on the same terms.
Attribution-NonCommercial-ShareAlike License code: (CC BY-NC-SA)	This license lets others remix, tweak, and build upon the owner's work non-commercially, as long as they credit the owner and license their new creations under the identical terms.
Attribution-NonCommercial-NoDerivatives License code: (CC BY-NC-ND)	This license is the most restrictive of the six main licenses, only allowing others to download the owner's works and share them with others as long as they credit the owner, but they can't change them in any way or use them commercially.

Table 9.2: Variants of the Creative Commons open license, after https://creativecommons.org/licenses/.

9.4 SUMMARY

Governments around the world are turning towards open data approaches and encouraging the use of their data by wide audiences. This follows extensive macroeconomic analyses demonstrating that making data open yields considerable economic and social benefits. Making water data open entails making it easy to discover, download and utilise, and applying an open license that makes it easy to share, remix and use the data. Many good examples of open licenses are available on the internet and can be implemented with minimal effort and cost. The *Open Data Commons* and the *Creative Commons* license groups are a recommended starting point when considering adoption of an open license.

72 Adapted from Creative Commons web site at https://creativecommons.org/licenses/

9.5 A KEY REFERENCE TO EXAMINE

Many countries have recently published studies exploring the virtues of open data in government. This document entitled *"Creating value through Open Data"*[73], published by the European Union, provides a detailed analysis of how making government data open can generate considerable social and economic value. It includes a macroeconomic analysis of the potential value of open data. Whilst this analysis does not focus on water data per se, it considers many of the common barriers and opportunities associated with adopting an open data approach to government data in general.

73 See https://www.europeandataportal.eu/sites/default/files/edp_creating_value_through_open_data_0.pdf

10
IMPLEMENT EFFECTIVE WATER DATA INFORMATION SYSTEMS

10.1 INTRODUCTION

Water data information systems are the vital pieces of software necessary for a wide range of water data management tasks, including data curation and information service delivery to end users. Whether the components of these systems are highly fragmented or tightly integrated, together they represent the foundations of most water data management workflows. As such, the capability and performance of water data information systems are a major determinant of the effectiveness of water data management arrangements. They also have a major bearing on the utility value of the water data itself as they affect how the information is utilized and by whom. For these reasons, it is desirable to devote attention and resources towards implementing effective water data information systems.

10.2 ATTRIBUTES OF EFFECTIVE WATER DATA INFORMATION SYSTEMS

So, what are the attributes of an effective water data information system? Some of the key attributes are mapped in Figure 10.1 and discussed below, relating to functionality, maintainability, spatial enablement and dependability.

10.3 FUNCTIONALITY

There are two aspects to the functionality of water information systems. The first is internally-facing and relates to the numerous water data curation tasks that need to be undertaken using the system. The second is externally-facing and relates to the water information services generated by the system for the benefit of water stakeholders.

Water data information systems are used for many different data curation tasks, including data importing, quality control, editing, transformation, analysis, archiving and distribution. The more of these tasks that can be formalised as repeatable business processes in a water information system, the better. To do so will enhance the efficiency and reliability of the tasks. Before selecting, developing or updating a water information system, it is therefore beneficial to have a clearly documented set of user requirements. Ideally, these user requirements would have three key characteristics.

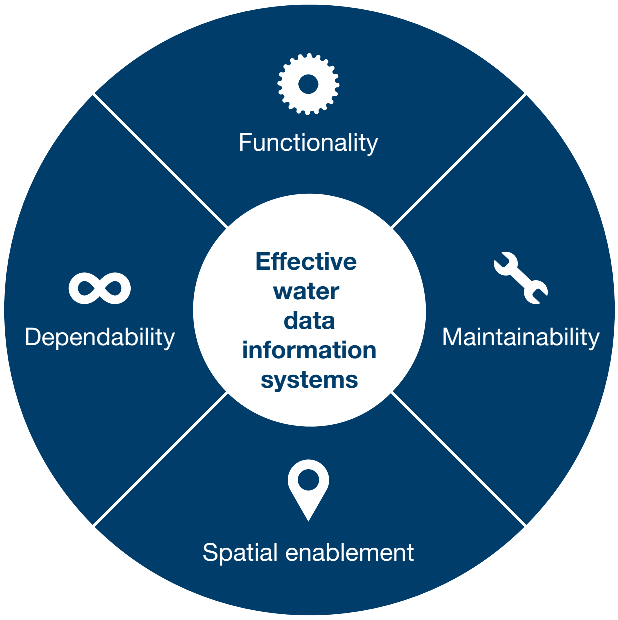


Figure 10.1: Some key attributes of an effective water information system.

First, they would encompass all of the anticipated water data curation workflows. Second, they would be developed with the specialist staff responsible for water data curation. Third, they would be 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 greatly enhanced when it is incorporated into water information services. Some popular examples of water information services include those focused on spatio-temporal variations in river discharge, trends in groundwater levels and extractions and fluctuations in reservoir storage volumes. Water foresighting 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. Such services enhance 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.

Water information services will be most useful when they are thoughtfully designed and implemented to meet the requirements of end users and the tasks they deem to be important. It is therefore beneficial to involve end users in the design process for water information services and to continually seek their feedback as they use the services. The user base and the amount of feedback for water information services will grow larger and faster if their availability and utility value are promoted through active marketing and communications.

Promotion may take the form of information sheets[74], videos[75] or online training materials[76]. Another way to enhance the adoption of water information services is to make them available as mobile apps on smartphones.[77]

10.4 MAINTAINABILITY

Water information systems are complex and therefore can be costly to maintain. In designing a new water information system 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[78].

Software systems sit at and between two 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 a unique ground-up development of a system. Whilst bespoke systems may use COTS products as sub-components, they are nevertheless a highly customized and unique instance of software. Many older water information systems were almost wholly bespoke solutions but nowadays, there are various COTS software solutions available on the market that can deliver most of the functions required of a water information system.

74 See information sheet example at http://www.bom.gov.au/water/about/publications/document/InfoSheet_18.pdf
75 See promotional video example at https://www.youtube.com/watch?v=7WOKXMOV2fk
76 See online training materials examples at http://www.bom.gov.au/water/geofabric/tutorials.shtml
77 See smartphone app example at http://www.bom.gov.au/apps/water/
78 See http://www.gartner.com/it-glossary/total-cost-of-ownership-tco

For water data agencies with limited IT development and support capacity, it is recommended to take the COTS path rather than to develop a bespoke system. This reduces development risk and the time required to implement a solution. Cost may not necessarily be cheaper, but is predictable, as COTS solutions require a known initial financial outlay to install, followed by a recurrent support licensing fee.

Two of the leading COTS solutions for water information systems are *Aquarius*™, provided by Aquatic Informatics[79] and *Wiski*™, provided by Kisters[80]. Both are enterprise-grade systems that provide many of the functions involved in managing time series-based water data. These include routines for data transformation, rating curve creation, data editing and quality control, data analysis and visualization, and web publishing. As noted earlier in Chapter 8 of these guidelines, both systems support Part 1 and Part 2 of the WaterML2.0 water data transfer standard. They also provide SCADA[81] capability for real time operations and rudimentary water forecasting tools. A significant advantage of these COTS solutions is that the many complex business processes instantiated within them have been validated as sound by leading water data management agencies. Other virtues of these systems are that they are under constant improvement (often at the request of customers) and supported by a large community of users that can be drawn upon for peer support.

However, these COTS solutions also have some limitations. For instance, their web publishing capabilities are reasonably limited, allowing only basic levels of customization. Likewise, they have very limited spatial analysis and spatial mapping capability. These limitations can be addressed by configuring the systems to interoperate with other COTS software packages that perform these tasks well. Examples might be a specialized data visualization package such as *Tableau*™ [82] and a Geographic Information System such as *ArcGIS*™ [83].

79 See http://aquaticinformatics.com/
80 See http://www.kisters.eu/water.html
81 Supervisory Control and Data Acquisition (SCADA) systems are used to monitor and process water data in real time and manage the networks used to collect the data
82 See https://www.tableau.com/
83 See examples of water-centric ArcGIS applications at http://www.esri.com/industries/water-resources

10.5 SPATIAL ENABLEMENT

Spatial enablement is the process of attaching relevant 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 it almost always possesses spatial attributes that are relevant to its 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 characterisation of the upslope contributing area. Likewise, the water level (or pressure) in a groundwater bore is a point-based observation that relates to a layer in an aquifer that occupies a three-dimensional volume with distinctive hydraulic characteristics. As such, fluctuations of water level (or pressure) at a point in an aquifer cannot be properly interpreted without characterising the dimensions and properties of the groundwater system.

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 to water stakeholders and decision-makers at the local level.

Spatial enablement of water data involves storing relevant spatial information layers in a Geographic Information System (GIS), along with the location coordinates for water data measurements. In the simplest case, those 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'.[84]

84 See http://www.bom.gov.au/water/geofabric/

The concept of a hydrological geospatial fabric was touched upon in Chapter 8 of these guidelines when discussing water data standards. It was noted that the WaterML2.0 standard under development, entitled "Part3: Surface Hydrology Features"[85], seeks to provide a standard method for defining fundamental relationships between different landscape geospatial elements that have hydrologic significance. These include hierarchies of catchments, river network topologies, canals, aquifers, reservoirs, wetlands and lakes.

85 See https://portal.opengeospatial.org/files/?artifact_id=72353&version=3

Though that standard is yet to be finalised, it is based on several hydrological geospatial fabrics that are already operational in the United States[86], Australia[87], Canada[88] and Europe[89]. 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.

86 See http://www.horizon-systems.com/NHDPlus/index.php
87 See http://www.bom.gov.au/water/geofabric/about.shtml
88 See http://open.canada.ca/data/en/dataset/87066e9a-94ee-680a-b1ba-591f4688db7d
89 See http://inspire.ec.europa.eu/id/document/tg/hy

10.6 DEPENDABILITY

Decision makers and water stakeholders depend on the continuous availability of water information systems. However, the continuous availability of any information system is difficult to accomplish for a variety of reasons. The systems must evolve over time and system code revisions sometimes go wrong, interrupting service. The computing hardware that systems reside on is susceptible to failure, either through a catastrophe like fire or flood, or a component failure like a disk crash. Any software system connected to the internet is vulnerable to cyberattack, which may result in the corruption of the system or a denial of service. These are just some of the many ways that stakeholders may be denied access to water information systems.

The most effective mitigation for such service interruption risks is to implement multiple instances of the water information system, ideally into four separate systems or computing environments. The primary instance is referred to as the 'production system', which is used for day-to-day operations. This should be housed in the most secure computing facility available and permissions to access it online should be restricted to the bare minimum number of people. The second is the 'failover system' which is a mirror image of the production system that would be invoked automatically in the event of a system interruption. This should be housed in a separate location and on separate hardware from that used by the production system. The third instance is the 'pre-production system', which is used for user acceptance testing of system revisions prior to change approval. This instance should be hosted on separate but identical hardware to that used by the production system. Ideally, pre-production versions of the water information system should never be too different from the production system, implying that system revisions should be made in many small steps rather than one big change. The fourth instance is the 'development system', which is used solely by developers as the test bed for new system functionality. Access arrangements to the development system need to be more liberal, so typically this instance is housed in a less secure, less restrictive environment that enables more staff to access the code. By maintaining these four separate instances of the water information system, it is possible to provide secure operations and an authentic and relatively risk free environment for system development and testing.

As noted above, physical security arrangements, backups and access control to system code 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.

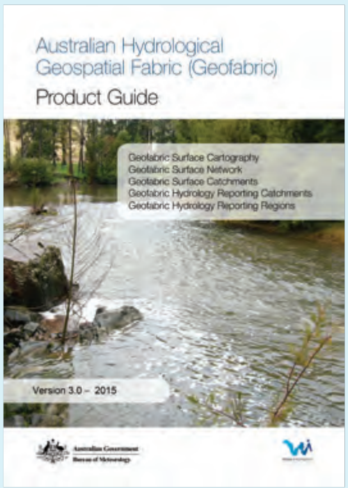
10.7 SUMMARY

Water data information 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 program. Hence, it is important to give careful regard to their design and operation. Water data information systems will be most effective when implemented with functionality, maintainability, spatial enablement and dependability at front of mind. Key goals should be to start with carefully prepared user requirements informed by internal and external stakeholder preferences, to adopt COTS software solutions when available, to link water data assets to a hydrological geospatial fabric, and to implement multiple instances of the system for security.

10.8 A KEY REFERENCE TO EXAMINE

Several publications and instructional resources are available on the Australian Hydrological Geospatial Fabric (AHGF) at the Australian Bureau of Meteorology web site.[90]

This document is a Product Guide for version 3.0 of the AHGF[91]. It provides a comprehensive description of the AHGF, its foundation data inputs and how they are transformed to create derived data products. It should be read in association with the prior version of the AHGF Product Guide, version 2.0.[92]



90 See http://www.bom.gov.au/water/geofabric/documentation.shtml
91 Available online at http://www.bom.gov.au/water/geofabric/documents/v3_0/ahgf_productguide_V3_0_release.pdf
92 Available online at http://www.bom.gov.au/water/geofabric/documents/v2_1/ahgf_productguide_V2_1_release.pdf

11
EMPLOY WATER DATA QUALITY MANAGEMENT PROCESSES

11.1 INTRODUCTION

Definitions for data quality are numerous but it may be thought of a composite term for multiple indicators such as data validity, accuracy, completeness, timeliness, consistency and availability. As in many other areas of data utilization, water data is most trusted and valued when its quality is assured. Hence, leading water data agencies employ various management procedures and systems to assure the quality of water data. These apply to all stages of the water data management process, from planning data acquisition to publishing water data services.

11.2 QUALITY MANAGEMENT AND ASSOCIATED TERMS

The definitive references for data quality and the procedures and systems deployed to achieve desired levels of data quality are published by the International Organization for Standardization (ISO), under the ISO 9000/9001 family of standards entitled *Quality Management Systems*.[93] Some of the key terms and concepts associated with data quality are summarised in Table 11.1.

93 See https://www.iso.org/iso-9001-quality-management.html

Term	Definition
Quality management (QM)	A process that focuses on achieving a desired level of data quality and the means to achieve it, encompassing quality control and quality assurance.
Quality management system (QMS)	The organizational structure, procedures, processes and resources needed to support a quality management process.
Quality control (QC)	Operational activities aimed at ensuring the data conforms to defined data quality standards.
Quality assurance (QA)	A system of documented procedures to monitor and evaluate the processes involved in a quality control program.
Certification	Formalised, independent accreditation that an agency's Quality Management System complies with the relevant ISO standards.

Table 11.1: Key concepts and definitions related to data quality management.

11.3 QUALITY MANAGEMENT PRINCIPLES APPLIED TO WATER DATA MANAGEMENT

Various bodies have adopted these standards and tailored them for application to their particular areas of activity. A key implementation of the ISO 9000/9001 standards that is of relevance to water data management agencies is the *Guide to the Implementation of a Quality Management System for National Meteorological and Hydrological Services*, published by WMO (2013).[94,95] This document sets out the steps required to implement a Quality Management System (QMS) in a National Hydrological and Meteorological Service (NHMS), with a particular focus on achieving ISO 9000/9001 certification.

The WMO has prepared additional guidance on QMS implementation, focusing more closely on water data agencies[96] and compiled a very useful checklist for QMS implementation in a national hydrological service.[97] These resources are complemented by informative case studies, summarising the experiences of four national hydrological services in implementing quality management systems, including Canada[98], the Czech Republic[99], New Zealand[100] and the United States[101].

94 *Guide to the Implementation of a Quality Management System for National Meteorological and Hydrological Services,* World Meteorological Organization (2013) Publication No. 1100.
95 Available free online at http://www.wmo.int/pages/prog/hwrp/qmf-h/documents/ext/wmo_1100_en.pdf
96 See http://www.wmo.int/pages/prog/hwrp/qmf-h/documents/Doc_3_GuidelinesQualityManagementSystem_17092013.pdf
97 See http://www.wmo.int/pages/prog/hwrp/qmf-h/checklist.php
98 See http://www.wmo.int/pages/prog/hwrp/qmf-h/documents/Case_Study-WaterSurveyCanada-Feb11_2016Final-13-10-2016.pdf
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100 See http://www.wmo.int/pages/prog/hwrp/qmf-h/documents/Case_Study_NZ_QMS_final.pdf
101 See http://www.wmo.int/pages/prog/hwrp/qmf-h/documents/USGS_WMO_QMS_Case_Study_Final.pdf

The four case studies reveal a variety of approaches taken and highlight multiple benefits accrued and valuable lessons learnt. They provide a good starting point for planning implementation of a QMS in a water data management agency.

Whether or not certification for ISO 9000/9001 compliance is sought, there is considerable benefit to be gained by integrating a QMS into water data management workflows. According to WMO (2013), some of the key benefits include:[102]

- A continuous improvement culture is embedded in the organization
- Customers' needs are identified, met and monitored within a consistent management framework
- Clear processes in place to address poor quality products
- Competencies are gained and maintained through appropriate training
- Well defined procedures and processes: employees know what to do and how to do it and don't waste time duplicating efforts
- The organization functions in a disciplined way as a result of the systematic approach to the handling of its activities
- Significant decrease in time and money spent on recurring problems as many are resolved permanently
- The organization builds the inner resources and skills to identify and resolve problems more expediently

102 This is a selective sample of benefits listed in section 2.7.1 of WMO (2013)

11.4 QUALITY CONTROLS IN WATER DATA MANAGEMENT

As highlighted in the four national case studies referred to previously, there is considerable variation in how water data management agencies employ QMS. There is even greater variation in the discrete Quality Controls (QC) that are included in the QMS, as these must be tailored to the specific water data management workflows that exist in each agency. Some examples of quality controls applied to water data management processes are listed in Table 11.2. It is important to note that, to be fully effective, quality controls need to be embedded throughout the entire water data management workflow.

Water data management processes	Examples of associated Quality Controls (QC)
Planning water data acquisition	• Specify user requirements • Document data acquisition procedures • Ensure staff are appropriately trained • Allocate specific responsibilities to staff • Periodically review monitoring objectives
Capturing water data from the field	• Use standard methods for data acquisition • Calibrate all measurement instruments • Validate measurements are accurate • Establish data entry controls • Maintain records on sites and instruments
Analysis of water samples in the lab	• Use standard methods for water analysis • Apply controlled labelling and recording • Ensure samples are stored securely • Maintain a clean laboratory environment • Regularly service analytical equipment
Processing water data prior to archiving	• Document all data processing procedures • Screen data for gaps and obvious errors • Verify all data conversions • Cross reference data for consistency • Assign data quality codes to all data
Archiving water data	• Use standard file transfer formats • Assign informative metadata to all data • Use logical file-naming conventions • Implement appropriate cybersecurity controls • Provide secure data backup
Publishing water data	• Ensure all data is easily discoverable • Export/publish all data in standard formats • Highlight data limitations to users • Articulate data use licensing conditions • Encourage user feedback on data quality

Table 11.2: Examples of quality control (QC) procedures relating to different stages of the water data management workflow.

To be fully effective, each of the quality controls should be documented, assigned to responsible staff and independently audited for compliance from time to time. Water data management procedures change over time and so should the relevant quality control procedures. Staffing arrangements in agencies are also subject to change so it is important to give consideration to succession planning and training, to ensure that quality management processes are not interrupted when key staff depart.

All water data agencies should aspire to at least define the quality of their water data holdings. Not all data has to be of the same quality, nor necessarily of a very high standard. But all water data sets should be indexed with some kind of quality code so that users can determine its fitness for purpose for different tasks.

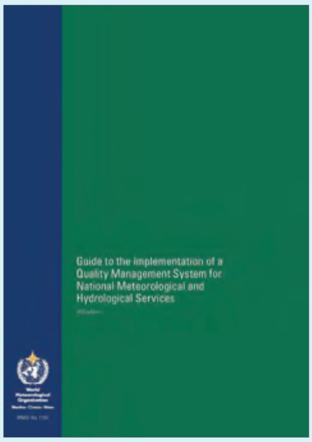
11.5 SUMMARY

The introduction of quality management procedures in water data management workflows can have a transformative effect on data quality. A structured quality management process not only engenders customer trust in the data but also yields considerable efficiencies in data management workflows. Having documented procedures provides clarity for staff involved in data management and a focus for their training. Formal certification against the ISO 9000/9001 standards has several benefits but is not necessary to make considerable advances in the improvement of water data quality. Discrete quality control (QC) procedures are applicable throughout the water data management workflow.

11.6 A KEY REFERENCE TO EXAMINE

The World Meteorological Organization (WMO) has invested considerable resources in defining the steps needed to embed quality management processes within National Hydrological and Meteorological Services (NHMS).

This WMO document, entitled "*Guide to the Implementation of a Quality Management System for National Meteorological and Hydrological Services*"[103] provides valuable step-by-step guidance for water data agencies in implementing QMS and for achieving ISO 9000/9001 certification.



103 Available free online at http://www.bom.gov.au/wmo/quality_management/forms/QM_Guide_NMHSs_V10.pdf

12
GETTING STARTED

12.1 INTRODUCTION

The previous chapters of these guidelines have explored the seven key elements of good water data management practice. These are:

- Identify the priority water management objectives
- Strengthen water data institutions
- Establish sustainable water data monitoring systems
- Adopt water data standards
- Embrace an open data approach to water data access and licensing
- Implement effective water data information systems
- Employ water data quality management processes

It has been argued that a comprehensive water data policy is one that gives attention to each of these seven elements and sets out a roadmap for reforming practice in each area. Each agency in each country will have a different capacity to achieve good practice, governed by their existing water management challenges, technical capacity, financial resources, public administration arrangements and political support.

Those with the most to achieve will likely be the ones that will need to take modest initial steps. What is most important is starting the reform journey and demonstrating the benefits that can be gained by improving water data management arrangements. This will help to build trust, then belief and eventually support. Hence, it is important to take a long-term, strategic view of the reform process and resist the temptation to over-promise what can be accomplished, particularly if resources and capacity are limited. Suffice it to say, the chances of success will be vastly improved if the proposed reforms are carefully planned, diligently executed and the resulting benefits clearly articulated.

It is always difficult to gather support for and then prosecute actions that are disruptive to the status quo and requiring considerable public investment. Planning the water data reform journey is every bit as challenging as implementing the reforms themselves. In the following sub-sections of this final chapter a series of steps are recommended that are worth considering when planning how to get started in reforming water data management arrangements.

12.2 TAKING STOCK OF CURRENT POLICY SETTINGS

Any reform plan must be preceded by a clear articulation of the current water data policy settings and compelling arguments regarding how they are failing. Some key questions that should be considered in such a stocktake are:

- Which institutions are involved in water data management and how?
- What are the relevant laws, policies and business imperatives governing their participation?
- What costs are borne by each participant in the water data sector?
- What are the deficiencies in water data collection and sharing?
- What are the missing technical competencies and technology gaps that need to be redressed?
- How are the current water data management arrangements failing to support the priority water management objectives?
- What is the opportunity cost of failing to reform the current policy settings?

In undertaking such a stocktake the aim is to erect a 'burning platform', a metaphor that emphasizes the criticality of urgent and transformative change due to dire circumstances. Most governments are short of resources and struggling with a long list of problems that need urgent attention. For this reason, the stocktake must convince the government that the current water data management arrangements are both seriously flawed *and* resulting in significant negative societal outcomes, be they economic, social or environmental. Potential investors are far more likely to be attentive to proposed reforms if such a case can be made.

12.3 PREPARING THE CASE FOR REFORM

Having erected the 'burning platform', the next challenge is to prepare proposed reforms that is politically, administratively and technically feasible. The proposal must also be financially realistic and represent a good return on investment.

These guidelines have set out the seven key elements of good water data management practice and it is expected that these elements will be prominent in any water data reform plan. The relative emphasis to be given to each of the seven key elements will depend entirely on the circumstances facing the country and the implementing agency.

Some of the critical elements to cover in the reform proposition are to:

- Be explicit about which water management challenges are addressed by the proposed reforms (see Chapter 5)
- Identify effective solutions for each of the problems identified in the stocktake
- Determine lead agency responsibility for the reform package
- Explain who will be affected by the proposed reforms and how
- Enumerate the full costs and benefits of each of the proposed reforms
- Provide detailed and realistic timelines for the package of proposed reforms
- Be clear about the sequencing of reforms and any vital dependencies
- Highlight the risks and risk mitigations for each of the proposed reforms
- Describe the project governance arrangements that will be enacted
- Include a 'Plan B' and 'Plan C' for the government to consider as alternatives to the preferred reform proposition, typically requiring less cost and disruption
- Build alliances with stakeholders likely to be consulted by government during their consideration of the reform proposal

The case for reform must strike a delicate balance between ambition and feasibility. There is no point designing a reform package that has little to no chance of gaining political and funding support. However, most significant reforms are a one-shot affair, so it makes good sense to scope out a comprehensive plan and seek support for it. Each country's circumstances will be different and the proponents of the water data management reforms must be sensitive to both the demand and supply sides of the reform proposition.

12.4 POSITIONING FOR EFFECTIVE IMPLEMENTATION

Having secured support for water data management reforms, the even greater challenge of implementation starts. The more complex the reforms, the greater the need for detailed planning, project management rigour and diligent governance. It is advisable to use a proven program/project management methodology such as PRINCE2[104] or PMP[105]. This should ensure that appropriate planning, documentation, scheduling, budgeting, reporting and governance is employed through the life of the implementation project.

It is vital to position for effective project implementation *before* the project starts. Large, complex projects are always risky to implement but the risks can be mitigated significantly by:

- Assigning implementation responsibility to a talented leader
- Recruiting the best possible people to seminal roles in the implementation team
- Building strong relationships within the implementing agency and with delivery partners
- Engaging talented innovation partners, whilst retaining strategic control of the project direction
- Organizing technical capacity in the implementation team along the lines of “build, operate and maintain”
- Developing strong technology foundations that will endure over time
- Investing in an effective communications and marketing capability to support the project

104 https://www.prince2.com/uk/what-is-prince2
105 https://www.pmi.org/certifications/types/project-management-pmp

12.5 CHAMPIONING THE REFORMS

Once the reforms are supported by government and funding is secured, it is vital to communicate the details of the reform package. This is particularly important for anyone that is to be involved in implementation or is affected by the reforms, either positively or negatively. It helps to identify respected, senior figures who can champion the reforms publicly, in order the amplify the merits of the new arrangements. Some of the communication actions worth considering include:

- Identify who should be communicated to, how and when
- Select the most appropriate communication channel for each sub-group of stakeholders
- Prepare and share compelling information products for each communication channel and sub-group of stakeholders
- Hold a launch event where the details of the reforms can be explained to stakeholders and celebrated
- Establish a feedback channel whereby stakeholders can provide advice, voice concerns and express support

The ease with which reforms can be implemented is highly dependent on the support given by stakeholders. Effective communication is critical for obtaining that support and should continue throughout the implementation phase until the reforms are complete and the new water data management arrangements become “business as usual”.

Photos:

p.10 Weir, Yemen (iStock © Sloot)

p.14 Oasis, Morocco (iStock © Pavliha)

p.20 Dam, France (iStock © Oleg Mitiukhin)

p.24 Jindabyne, Australia (iStock © FiledIMAGE)

p.29 Water tank, Yemen (© Argent)

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p.45 Treatment plant, Iran (© Western)

p.53 Waterfront, Greece (© Argent)

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