



## Chapter 13

# Bridging the observational gap

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### Key messages

- ◆ Worldwide, water observation networks provide incomplete and incompatible data on water quantity and quality for managing water resources and predicting future needs – and these networks are in jeopardy of further decline. Also, no comprehensive information exists on wastewater generation and treatment and receiving water quality on a regional or global scale.
- ◆ There is little sharing of hydrologic data, due largely to limited physical access to data, policy and security issues; lack of agreed protocols for sharing; and commercial considerations. This hampers regional and global projects that have to build on shared datasets for scientific and applications-oriented purposes, such as seasonal regional hydrologic outlooks, forecasting, disaster warning and prevention, and integrated water resources management in transboundary basins.
- ◆ Improving water resources management requires investments in monitoring and more efficient use of existing data, including traditional ground-based observations and newer satellite-based data products. Most countries, developed and developing, need to give greater attention and more resources to monitoring, observations and continual assessments of the status of water resources.

There is little doubt that global hydrologic data are inadequate in both spatial coverage and frequency of observations. Moreover, hydrologic observation networks are worsening in many countries because of changing national investment priorities and declining human capacity.<sup>1</sup>

Beyond physical inadequacy, there is widespread reluctance to share hydrologic data, largely because of inadequate national administrative procedures and mechanisms, issues related to commercial use of hydrologic data and information, and security concerns and political sensitivities about transboundary resources. Sharing is also hampered by inadequate telecommunications systems. But the main reason for the decline of networks is insufficient awareness of the global value of hydrologic data.

### The importance of hydrologic observations

Sound water resources management should be based on a quantitative understanding of the state of the resource. Because the components of the water cycle vary over time, long time series of observational data are essential. Lack of such data compromises the validity of information used for assessments and subsequent decision-making.

When sufficient observational data are lacking, models can be used to generate information for decision-making, provided they have a baseline from which to be calibrated. But synthetically generated data cannot substitute for real-world observations. To keep networks affordable and sustainable, a minimum-density network



can effectively coexist with model-derived data and information. Established analytical procedures can offer insight into observational and model uncertainties and provide a basis for thoroughly analysing permissible reduction of information as a result of minimizing networks.

Data are also crucial to improving understanding of the hydrologic cycle for weather- and climate-related science and for water resources management through better assessment methods and improved forecasting services that can reduce disaster damages. One justification for improving hydrologic networks is to minimize uncertainties in hydrologic forecasting and prediction and therefore to minimize decision-making risk. This can be achieved in several ways, including new and better-quality information from improved measurements (quantity, quality, timeliness) and measurement techniques, improved model structures based on better understanding of physical processes, and better mathematical representation and use of available information during model identification and calibration.

Aside from technical considerations, uncertainty in hydrologic data can be attributed to the general inadequacy of observations in spatial and temporal coverage. 'Uncertainty' in this context relates to the adequacy and quality of technical observations for forecasting and assessment – not to the aberrations in technical observations. Uncertainty for assessment and forecasting varies, but is generally high in subtropical and tropical regions as well as polar and mountainous regions. Developing countries, especially the least developed countries, generally have inadequate networks associated with a high uncertainty of hydrologic observations.

There is a critical need for more availability and access to global hydrologic data, information and products for climate and hydrologic research and applications – including the validation and refinement of global circulation models and the quantification of the water balance and its variation over large basins and regions up to the global level. Important scientific issues include the quantification of a postulated accelerated hydrologic cycle as a result of global warming and the contribution of continental runoff to sea level change. In a general sense global hydrologic observations help quantify key environmental and human-induced changes and interactions, identify significant trends, assess

variability of freshwater resources and develop adequate response strategies.

While characterizing all components of the water cycle (including water quantity and quality, groundwater and surface water) is important, measuring everything is impractical. The components of surface water measured most frequently are precipitation, streamflow, evaporation and water in storage (reservoirs and natural lakes). Other components (soil moisture, for example) are generally quantified using models that rely on the other measurements. The components of groundwater measured most frequently are inputs (recharge and inflow), aquifer storage capacity and natural outflows. While effective management of groundwater resources depends on measuring these components, none can be measured directly as a single value because they all depend on a large number of variables.

Water quality observation networks are sparse and frequently use spot rather than continuous observations. The numerous water quality variables that determine how water can be used and the treatment technologies required for safe use make it very difficult to design effective and affordable monitoring systems and to identify relationships between water quantity and quality variations. Such information can be extrapolated to sites that have no observations. The problem is exacerbated when natural water quality is modified by both point and diffuse anthropogenic pollution sources. And deteriorating water quality greatly affects the potential use of water, increasing the need for networks of water quality observations.

It is recognized worldwide that management of water resources should be environmentally sustainable and that adequate protection of aquatic ecosystems is extremely important. Aquatic ecosystems are sensitive to changes in water quantity and quality, but the precise manner in which they react to changes in abiotic drivers is poorly understood. Better understanding is vital for allocating water and can be achieved only by monitoring abiotic drivers (flow and water quality) and biotic responses (biomonitoring of biological conditions; see chapter 8).<sup>2</sup>

### Recent developments in observation methods, networks and monitoring

The adequacy of any hydrologic observation network is related to the accuracy of

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**The adequacy of observational networks varies widely by region, but observations for many water cycle variables have inadequate spatial and temporal coverage**

measurement systems, the density and representativeness of the network, and monitoring, data retrieval, storage and dissemination practices.

Observational errors are generally minimal when instruments are used in environments and under conditions for which they were designed. But instruments must be well maintained and calibrated, and rigid quality management procedures must be observed from the field to the release of the primary data. Further reducing instrument errors is less critical than expanding operational networks to decrease observation uncertainties. Error bandwidths have not been significantly reduced, due mainly to inadequate network densities, poor quality and control over hydrologic observations and insufficient hydrologic data and information.<sup>3</sup>

The adequacy of observational networks varies widely by region, but observations for many water cycle variables have inadequate spatial and temporal coverage.<sup>4</sup> Continuously and consistently quantifying hydrologic variables at the global, regional and basin levels will require integrated observation systems that use both terrestrial and satellite observations. These systems will need data assimilation products, including models calibrated from the integrated networks and multiplatform observations.

Most of today's data for terrestrial observations and for many satellite observations are funded through national agencies, although satellite observations are increasingly carried out in the framework of multinational agreements. It would be worthwhile to investigate whether selected terrestrial observations could also be carried out under multinational agreements. Given the resource inputs from national agencies, product development and other derived services need to be responsive to national requirements to encourage continued national participation and funding.

A close feedback loop needs to be established between national data providers and the users of global observation systems. For developing countries this requires more participation in global projects. Most information generated from global observation networks is used by developed countries, and much less is used by developing countries. Sharing information across regions, however, becomes increasingly valuable – especially for smaller countries, which can complement their spatially or technologically restricted national observation networks, and for

hydrometeorological variables and hydrologic data and information from shared river basins used for forecasting.

For network development and the design of multiplatform hydrologic observation systems, the heterogeneity of research fields makes it difficult to decide what variables should be collected and over what time and space. Network requirements also vary depending on the requirements of the research and application communities. A flexible network architecture with networks as subsets of larger composite networks or observation systems is thus desirable. Minimum operational baseline networks of routine observations (ground- and satellite-based) need to be augmented by research networks on a long-term basis.

Growing demand for precise assessments, forecasting and warnings requires quality management frameworks for all observation systems. The value of data depends on the accuracy and comparability of observations from different entities and instruments (including analytical laboratory procedures). Although regulatory data quality frameworks exist at the national and international levels, their implementation and adherence vary widely and are insufficiently documented from the country level to higher levels. Lack of adherence is frequently related to insufficient technical training of staff involved in measuring and managing data observations. The results are inadequately and irregularly calibrated instruments, few intercomparisons of different observation methods and analytical procedures, poor data quality control measures for consistency and homogeneity (the identification of systematic trends due to environmental or instrumental changes) and a lack of interaction and experience sharing among institutions.

Objective assessment of data quality is rare but nonetheless indispensable for reliably using data in decision-making. For various reasons, including poor quality and security considerations, several data providers are hesitant to share data. In developing countries the attitude exists that collecting some data (of questionable reliability) is better than collecting no data at all. But confidence in good-quality data can be an incentive to share the data with other countries, development programmes and partners.

### **Changing status of operational data over the recent past**

This section examines the status of operational data from terrestrial hydrologic



networks, multiple uses of national hydrologic observing systems, integration of multisource observations, the sharing of observations, observations and data on water use, and hydrologic observations from space.

### State of terrestrial hydrologic networks

For terrestrial hydrologic observation systems, especially in many developing countries, data collection is inadequate and deteriorating. Many systems lack adequate quality assurance and control standards for calibrating instruments and reducing data. And basic capacity to access, interpret and apply water cycle information from both terrestrial and satellite observation systems is often insufficient.<sup>5</sup>

Many terrestrial hydrologic networks are shrinking for several reasons:

- Available records fulfil present hydrologic information requirements.
- No direct economically justifiable use of hydrologic information is apparent (for example, in pristine basins or stations close to the mouths of rivers and delta areas).
- Logistical problems.
- Budgetary or resource problems.

While the overall number of streamflow stations did not change significantly, stations with a long-term record were most affected by closures. The US Geological Survey reports that from 1980 to 2004, 2,051 stream gauges with 30 or more years of streamflow data were discontinued, leaving 7,360 at the end of 2005.<sup>6</sup> An important source of global hydrologic memory is being lost at a time when such information is needed to characterize the impacts of climate variability and change on hydrology and water resources. Another example is Kyrgyzstan in the Aral Sea basin, one of the best documented environmental disaster cases, where the number of hydrologic stations declined 48% during 1985-2005.<sup>7</sup>

The technical challenges behind the current situation of hydrologic data in Africa can be traced to the low quality and quantity of basic equipment, poor technology, few laboratories for recalibrating equipment, inadequately trained human resources at both professional and technician levels and insufficient funding and capital to sustain current

operations or access new technologies.<sup>8</sup> Many challenges in accessing datasets in Africa arise from the reluctance of countries to exchange data freely. One reason: many countries do not feel sufficiently involved in regional or global studies and believe that their data services are not appreciated. Other factors are the absence of protocols and conventions for sharing water in some shared or international basins and aquifers, limited feedback from researchers and studies that use African data and fear of losing ownership of data.<sup>9</sup>

Anecdotal evidence (because no globally representative studies are available) and reviews of funding in the water sector suggest that national agencies and donors are not prepared to invest in multipurpose hydrologic networks expanding to regional or global hydrologic networks. But ongoing projects include new gauging stations at a limited scale, though these stations often operate only for a limited time for specific projects (including scoping projects, such as for proposed irrigation schemes) and rarely have historic records.

One major effort to stem the decline of hydrologic networks is the World Meteorological Organization's World Hydrological Cycle Observation System. Implemented at the regional and transboundary river basin levels, the programme focuses on establishing and operating requirements-driven hydrologic information systems.<sup>10</sup>

There is no systematic monitoring of groundwater, which constitutes 21% of the world's freshwater resources, at the regional or global level.<sup>11</sup> Few of the publicly accessible systems that contain relevant general information on water at the global level store data on groundwater quantity or quality. In many countries little attention is paid to the uniformity of hydrogeological data, precluding cross-comparisons. Few countries have up-to-date groundwater databases from which the current quality and quantity of groundwater resources can be elaborated. Without such systems information is obtained from model-derived data.

Information availability differs across time and space, as do the methods used to process this information. To address this situation, the International Groundwater Resources Centre has established the Global Groundwater Monitoring Network, which uses available data and derived information to periodically assess global groundwater resources.

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**Major investments are needed to reverse the decline of hydrologic observation networks, including surface water and groundwater observations and water quality monitoring**

Surface observations reveal only indirect indicators of groundwater system status, such as changes in vegetation patterns, changes in river base flows, appearing or disappearing springs and wetlands, land subsidence and visible changes in the water levels of shallow, large-diameter wells. Subsurface observations are required to quantify groundwater storage through variations in groundwater levels, changing aquifer conditions and alterations in the chemical composition of groundwater. Groundwater levels and water sample collection are carried out using observation wells. Advanced data loggers such as pressure transducers and salinity sensors allow groundwater and salinity levels to be automatically measured at variable intervals. Geophysical methods (well logs and surface studies) help reveal changes in moisture content and salinity and trace some pollutants. There is promising evidence that gravimetric remote sensing methods allow aquifer monitoring on global to subregional levels, especially in sparsely gauged areas.<sup>12</sup>

The availability of usable freshwater is determined not only by the quantity of the resource but increasingly by its quality, which may further reduce the net availability of water resources for different uses and have critical environmental consequences. More than 100 countries contribute to the Global Environment Monitoring System – Water, a programme with more than 3,000 stations operated by Environment Canada under the auspices of the United Nations Environment Programme. The global database that it has built is key for global freshwater quality assessment. But a general lack of institutionalized, continuous dataflow into the database severely hampers further regional and global assessments as well as programmes to improve water quality, especially in transboundary basins.<sup>13</sup>

National data holdings are frequently fragmented, with no metadata catalogue in place that allows a complete picture of a country's water quality situation. Notwithstanding some positive examples, monitoring networks in developing countries are rudimentary, irregularly updated, rarely objective driven and without sufficient quality control to make observations truly useful. It would be a formidable task not only to establish sustainable baseline and specialized water quality observation networks, but also to make them inter-operable with surface water and groundwater quantity observations that enable

calculating pollutant loads and biogeochemical fluxes, for example.

Observational gaps result from failure to observe and collect data or from lack of access to data. Increasingly, the gaps are due to lost data and information as a result of disasters, social unrest and technological evolution. Data rescue programmes are thus crucial to retaining historical information and to expanding knowledge bases as far back as possible. This is especially important when considering that long records of observations are a prerequisite for detecting climate variability and changes in observations as well as for establishing the baseline hydrologic conditions that existed prior to development activities.

Major investments are needed to reverse the decline of hydrologic observation networks, including surface water and groundwater observations and water quality monitoring. National investment can be mobilized with assistance from development partners, but doing so is very difficult when investments are sought for transboundary hydrologic observation systems or global data collection and monitoring systems. This is partly due to the fact that most development partners, including institutional donors, focus their technical assistance on bilateral needs rather than on regional or global observing systems.

The general trends of in-situ observation methods include:

- Increasing use of automatic logging systems and replacement of instruments with mechanical recording devices.
- Widespread use of motionless observing methods, including measurement of hydrostatic pressure for gauge heights and observation methods without water contact, such as instruments using small radar devices suspended over the water surface to obtain gauge heights.
- Coupling of in-situ stations with automatic data transmission and telecommunications systems, including mobile phone communication using Global System for Mobile/General Packet Radio Service standards.
- Increasing integration of in-situ observation systems with basinwide hydrologic information systems, including forecasting and decision-support systems.



### Observation networks for different purposes

National hydrologic observation networks often serve several purposes – such as providing information for water resources assessments and forecasting and serving as least influenced baseline hydrologic stations for climate studies. A clear delineation of national hydrologic observation systems for different uses is the exception rather than the rule. Specialized hydrologic networks are justified, especially when regular network observations do not provide the appropriate specific observations. One example is the need for extreme event data, which are generally less available than regular network observations.

Justifying networks with higher observational density and higher reporting frequency needs to be based on multiple-objective requirements analysis to assess additional economic or scientific value gained. The rational use of national hydrologic networks would be enhanced by clearly delineating priority use of stations based on such criteria as quality of data, length of records, location of the station and reporting cycle. Classifying hydrologic networks this way would allow rapid identification of subnetworks for specialized purposes. Of particular interest would be hydrologic stations recording flows of water to and from national territories to support assessment of the resource at the national level. In addition, observational networks are sometimes established for specific purposes – in particular for environmental assessment studies. Most of these stations are operated for only a limited time, and their data deliveries are generally poorly documented. One recommendation is to document and preserve short-duration hydrologic observations to supplement regular national hydrologic networks.

### From data to information – integrating observations

Hydrologic forecasting and assessment products increasingly use multisource observations and complex data assimilation algorithms to improve accuracy, reliability and timeliness. For example, flood forecasts can be based on observations of precipitation from conventional rain gauges, hydrologic radars and satellite precipitation estimates combined with current (real-time) measurements of soil moisture and other variables. Thus, aside from technical opportunities and challenges, integrating multiple observation systems that operate at different spatial and temporal scales requires systems to

ensure internally consistent data products, keeping in mind that local, regional and global datasets are equally important because they serve different purposes.

### Sharing hydrologic observations

Other than technical obstacles, sharing of hydrologic data can be hampered by limited physical access to data, national data policy and security issues, lack of agreed protocols for sharing and commercial considerations. Whether hydrologic data are a public good or commodity does not have a simple answer. One argument is that data do not have an intrinsic value and therefore are not commercial products. Societal, scientific and commercial value is added as a result of information and service delivery products (such as hydrologic forecasts or assessments) that have identifiable and quantifiable socioeconomic values. For example, flood disaster damages are often less when an effective forecasting service exists. The cost-benefit ratio for hydrologic data used for forecasting ranges from 1:10 to 1:15.<sup>14</sup>

The basis for sharing data and information is defined requirements from national sectors, planning commissions, river basin organizations, hydrologic and climate research communities, and national and regional development partners. Commercial entities, including the public utility sector, are also increasing requirements for shared hydrologic data. A needs-based approach should form the basis of any data-sharing policy. Many data-sharing protocols and agreements already exist at the national, regional and global levels. Data-sharing agreements between riparian countries in transboundary basins where lower riparian countries have a disproportionately larger benefit from upstream observations could also require downstream users to contribute to the maintenance and operation of upstream stations in order to ensure long-term availability of hydrologic observations. Generally, scientific and technological advances and better management of water resources and hydrologic forecasting at all levels should not be hampered by restrictions in data-sharing arrangements.

The United Nations Economic Commission for Europe Convention on the Protection and Use of Transboundary Watercourses and International Lakes requires its parties to exchange data on water quality and quantity and pollution sources as well as environmental conditions of transboundary waters. The first Assessment of Transboundary Rivers, Lakes and Groundwaters in the region,

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developed under the Water Convention in 2007, describes the hydrologic regime of 140 transboundary rivers, 30 transboundary lakes and 70 transboundary aquifers together with pressure factors in their basins, their status and transboundary impact, as well as trends and envisaged management measures.<sup>15</sup>

Observational gaps also arise when hydrologic observations are not shared. Regional differences in data provided to the Global Runoff Data Centre are apparent in both quantity and timeliness. Hydrologic data from North and Central America, the Caribbean, Europe and Mediterranean Asia are far greater than data from other regions (map 13.1). In other regions few hydrologic stations provide data to the centre, and update intervals are too great (figure 13.1). The paucity of contributions is often related not to lack of infrastructure but to general unwillingness to share data in an institutionalized, regular manner. This regional picture also suggests that most data are shared by a rather constant number of national hydrologic services, with few new services added over time. This hampers regional and global projects that have to build on such datasets for scientific and applications-oriented purposes. Examples include the calibration of models to provide seasonal regional hydrologic outlooks, forecasting, disaster warning and prevention, and water management in transboundary basins.

Inadequate use of current information technologies severely threatens data and information sharing even when basic

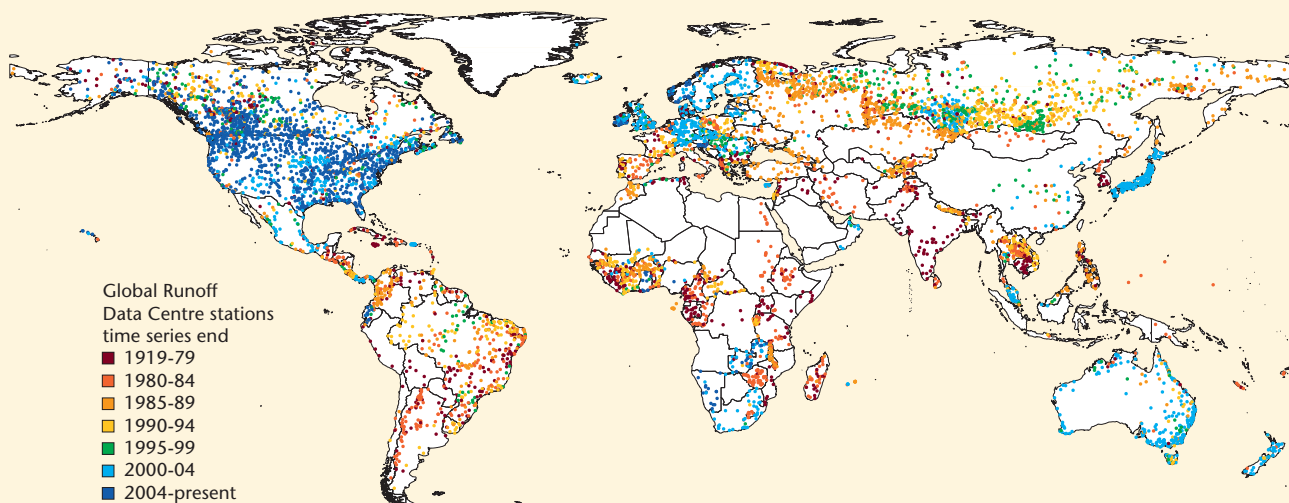
hydrologic observations are available. Typical inadequacies relate to incompatible information systems, which effectively block the seamless exchange of data and information between systems and different operators and programmes from the national to the global level. These inadequacies lead to an effective blackout of potentially valuable data and information because they are not part of the information management cycle. The situation is especially critical for forecasting purposes when data need to be shared in real or near real time.

#### Observations and data related to water use

Many models used to extrapolate from observations to areas with no observations available are designed to simulate natural conditions based on hydrometeorological inputs. For model outputs to reflect quantitative changes of water resources availability and use over space and time, model components that simulate anthropogenic development impacts (such as population trends, economic activities and land use changes) need to be integrated. Model calibration and validation likewise rely on information on water storage in lakes and reservoirs, water abstractions and return flows.

Global data on water use exist primarily for the agricultural sector (for example, the AQUASTAT database by the Food and Agriculture Organization of the United Nations). Data on consumptive and non-consumptive use of water resources are not a regular part of many national statistics,

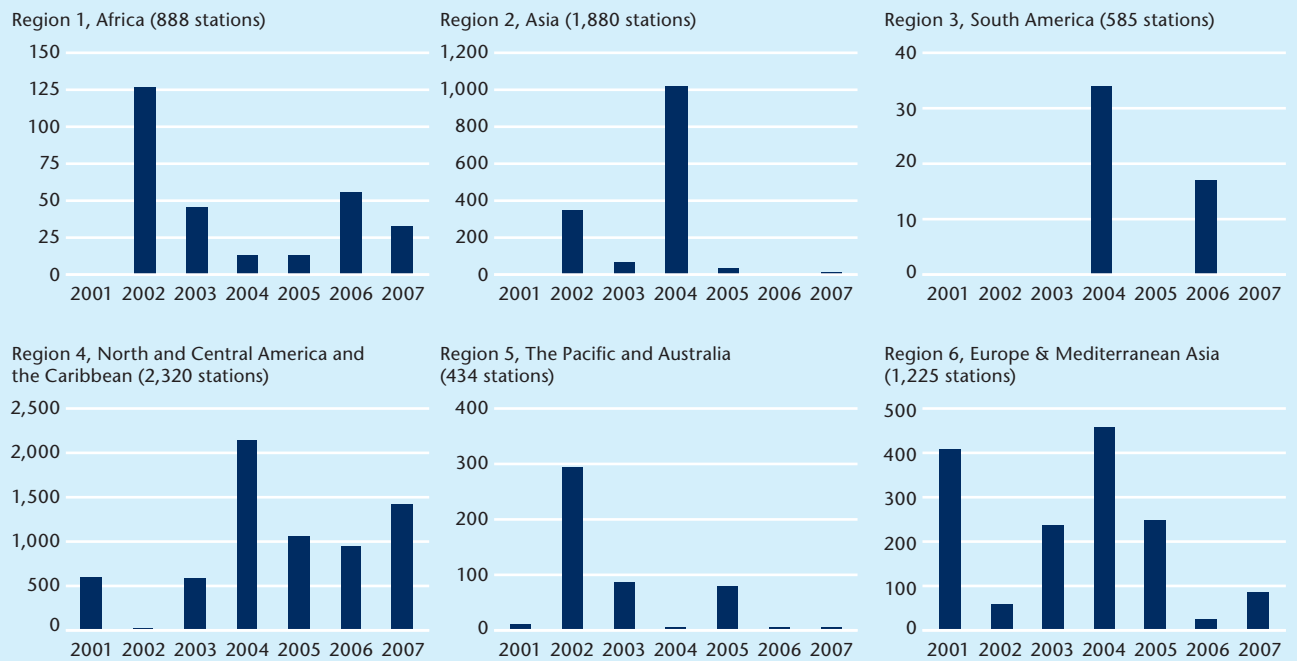
Map 13.1 Distribution of Global Runoff Data Centre streamflow gauges



Source: Global Runoff Data Centre (<http://grdc.bafg.de/>).



Figure 13.1 Data delivery rate from runoff gauging stations to the Global Runoff Data Centre (number of stations from which data have been received, 2001-07)



Note: Regions are World Meteorological Organization classifications.  
Source: Global Runoff Data Centre (<http://grdc.bafg.de/>).

although where abstractions are licensed, information on the maximum use of water may be available. This situation is unsatisfactory because it prevents effective management of water demand relative to availability and supply of freshwater.

Despite the importance for the integrated management of water quantity and quality and for understanding water-related health hazards, no comprehensive information exists on the regional or global extent of wastewater generation and treatment and receiving water quality. Even at the national level such information is either inconsistently gathered or unavailable – partly because of ill-defined data collection responsibilities that rest with a multitude of national organizations and commercial entities that rarely share their information.

### Hydrologic observations from space

Satellite observations are important means for providing hydrologic data with acceptable spatial and temporal resolution, especially in areas with no or limited infrastructure. However, 'acceptable resolution' depends on what the data are to be used for. In-situ data provide acceptable coverage and temporal resolution mainly in more accessible regions. In-situ data are also used for calibrating and validating space-based information, hydrologic or water resources models and routine real-

time forecasting services. For forecasting of runoff and water flows, data must be available within a fraction of an hour up to several hours, depending on the size of the basin and forecasting requirements. For assessment a temporal resolution of several weeks up to one month may suffice.

High priority for additional observations should be focused on data-poor regions, poorly observed hydrologic variables, regions sensitive to change and variables with inadequate spatial resolution. The need for satellite-based observations that complement in-situ observations should be recognized. In-situ and space-based observations for hydrologic applications need to be integrated in a comparable space and time domain and under tight quality control. Such quality control would require increased efforts to assess observation quality through intercomparison and recalibration projects. This is especially important for achieving continuity between historical terrestrial observations and new satellite observations.

Terrestrial water level observations can now be supplemented with sufficient accuracy by radar altimetry instruments flown on the Envisat, Jason and TOPEX satellites. Because the sensor carriers on these satellites are not geostationary, the altimetry observations are taken at virtual gauging



**Merging data streams from both terrestrial and space-based observations will require new model structures that need to be tested for their utility in operational services**

stations along the path of the satellite at various stretches of a river with an approximately weekly repetition cycle. This allows for basinwide hydrologic assessments. Efforts are under way to derive discharge time series from altimetry observations through actual rating curves that use the river morphology and through virtual calibration curves that use idealized channel profiles in combination with hydraulic parameters. The use of altimetry observations is, however, restricted to large rivers, lakes and reservoirs and is not appropriate for smaller tributaries.

Since 2002 gravimetric measurements using the Gravity Recovery and Climate Experiment (GRACE) satellite have provided the means to observe changes in large aquifers at a spatial scale over 40,000 square kilometres. However, separating water masses (soil moisture, vegetation and groundwater) is still difficult. Inverse approaches are therefore needed to separate the hydrologic contributions of the main water reservoirs (oceans, atmosphere and total continental water storage including snow, soil wetness, groundwater and ice caps) from monthly synthetic GRACE geoids. Nevertheless, at large scales gravimetric observations of changes in large aquifers from GRACE and next-generation missions like the Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) satellite are nearing a stage where they could be used operationally.

Apart from directly measuring hydrologic variables such as water levels, snow and ice cover extent, soil moisture and groundwater, satellites are invaluable for providing information for hydrologic estimation (modelling) studies. Satellite estimates of precipitation are an obvious example. Several precipitation estimation methods based on microwave and infrared instruments on numerous satellites and associated different data retrieval and interpretation algorithms have reached a semi-operational and, in a few cases, an operational level.<sup>16</sup> Some global or near-global precipitation products have spatial resolutions down to 4 kilometres and temporal resolutions down to three-hourly, making them useful for water management and flood forecasting. Several hydrology-relevant products are associated with the Moderate Resolution Imaging Spectroradiometer instrument operating on both the Terra and Aqua spacecraft: inundation areas, surface changes of lakes and reservoirs, surface reflectance, temperature, land cover and indexes of vegetation change.

## Opportunities and challenges

The combination of observations from GRACE, GOCE, satellite altimetry and other space systems such as active and passive microwaves, satellite radar interferometry and visible and radar imagery offer the potential for developing new hydrologic products, such as present-day satellite-derived precipitation products and the planned Global Precipitation Mission.

Near-future developments are likely to include the operational generation of truly multiplatform information products from terrestrial observations merged with gravimetric observations from GRACE and GOCE, radar altimetry and precipitation estimates as inputs into hydrologic models for forecasting, water resources assessment and monitoring of the water balance of basins. Likewise, merged multiplatform information can be used to quantify spatial and temporal variations of flooded areas and water volumes. The improved cooperation between the national meteorological and hydrologic services of many countries with the aim to improve hydrologic forecasting is at the heart of the World Meteorological Organization Flood Forecasting Initiative, launched in 2003. The availability of multiplatform, multivariate data streams in near real time and with high accuracy will be crucial to achieving this goal.

Using the global concept of the World Hydrological Cycle Observing System, building on terrestrial hydrologic information systems and obtaining global hydrologic coverage from satellites to integrate terrestrial and satellite-based observations could close many gaps in hydrologic observations at all levels and support improved hydrologic and water resources assessments, forecasting and research. To make full use of satellite observations, a suite of intercomparison and validation projects is needed to assess the accuracy of satellite-based observations with terrestrial observations in a wide range of environmental conditions. Merging data streams from both terrestrial and space-based observations will require new model structures that need to be tested for their utility in operational services.

Despite current technological and methodological developments, an important challenge remains. To mainstream satellite-based observations that complement terrestrial observations in operational water resources management and forecasting services on a routine basis and



for critical assessments, awareness and capacity are needed in national meteorological and hydrologic agencies. Likewise, space organizations need to know the requirements for space-based observations in order to design and operate new and tailor-made missions and to create derived observational and model products for hydrology and water resources management. Space agencies will need to develop front-end tools that allow primary data to be converted into graphics and tables that can be used in models and forecasting routines. This will require an intensified dialogue among space agencies, the science community and hydrologic and meteorologic services to define interinstitutional cooperation and sharing of responsibilities on long-term archiving of satellite observations, access to data and information in support of science and research, and the development of products for operational applications.

### Some suggestions for bridging the observational gap

Meta-information systems that promote information rescue and institutional sustainability of water information and knowledge are prerequisites for all levels of water management. Meta-information systems provide generic information about data, information, knowledge sources and data products that are applicable to operations and research. Online dedicated global information systems-based applications can improve access to information. Through a geographic interface and standardized set of water-related attributes, information can be seen in spatial context that shows analogies and patterns. Such applications are indispensable for the global sharing of information and apply to all components of the water cycle.

In addition to the key messages of this chapter, other important steps can be taken to improve the current situation of severe observational gaps in hydrologic observations include:

- At the national, regional and global levels a minimum requirements analysis of long-term, multipurpose observational needs should be undertaken; a new requirement is climate-relevant

observations, including those from pristine basins.

- Financing of hydrologic networks, including operation and maintenance, should be based on a multiple-source strategy rather than the prevailing single-source, sector-specific funding arrangements.
- Integrated multiplatform network solutions that combine in-situ and space-based observations and that are affordable for developing countries should be promoted. This would enhance the observational base in spatial and temporal coverage.
- Other hydrologic information – such as in-situ and remotely sensed soil moisture and meteorological data and information including precipitation, evaporation, humidity, temperature and wind fields – needs to be considered to complement hydrologic information and to enhance the information content of hydrologic data through integration in multivariate models and predictions.
- In data-sparse regions in particular, modelling approaches need to be mainstreamed to generate model-derived observation time series. A promising tool is the reconstruction of hydroclimatic data by downscaling. Datasets from the National Centers for Environmental Prediction/ National Center for Atmospheric Research for 1948-2007 are a widely used source.
- As observational gaps are often directly related to deficiencies in data transmission and communication, this could be overcome to a large degree by connecting offline operating stations to modern telecommunication systems to increase spatial and temporal availability of data from already existing stations.
- Making maximum use of existing hydrologic observations requires more effort to share hydrologic data and information on all levels, including transboundary river basins and shared aquifer systems.

**Online dedicated global information systems-based applications are indispensable for the global sharing of information and apply to all components of the water cycle**



### Notes

1. GCOS 2003b; US Geological Survey n.d.
2. Personal communication with Richard Robarts, Global Environment Monitoring System–Water.
3. Based on author's discussions with instrument manufactures such as OTT and SEBA.
4. GCOS 2003b.
5. GCOS 2003b.
6. US Geological Survey n.d.
7. Grabs 2007a; and presentation by Kyrgyzstan Hydromet at an ARAL-HYCOS planning meeting, 6-7 December 2006, Almaty.
8. GCOS 2003a.
9. GCPS 2003a.
10. World Hydrological Cycle Observing System ([www.whycos.org](http://www.whycos.org)).
11. Based on data from the International Groundwater Resources Assessment Centre.
12. Grabs 2007b.
13. GEMS-Water 2008.

14. WRI 2004.
15. UNECE 2007.
16. Grabs 2007b.

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