The regional project Sustainable Use of Transboundary Water Resources and Water Security Management (WATER SUM) addresses water-related challenges and promotes regional cooperation in the Middle East and North Africa (MENA) through two project components: Water Resources Management Good Practices and Knowledge Transfer (WATER PORT); and Water Security (WaSe). The WATER PORT component focuses on building skills and transferring knowledge on integrated water resources management in order to promote sustainable development and climate adaptation. The WaSe component supports the introduction of local water security action plans to help communities withstand asset scarcity and tackle environment-related conflicts.

The overall objective of the WATER SUM project is to promote and enhance the sustainability of managing water resources in beneficiary countries in the MENA region in order to halt the downward spiral of poverty and to reduce biodiversity loss and environmental degradation. The main expected impact is institutional and behavioural change in water governance and utilisation patterns. This will be achieved through the successful transfer of knowledge and skills to all participating actors in the water management arena. Additional impacts related to improving water security are also significant in terms of overall environmental security. It is therefore vital to build partnerships in order to address environmental asset scarcity, environmental risks or adverse changes, and environment-related tensions or conflicts, as this is the most effective means for delivering development and conservation targets to local communities and beyond.

The WATER SUM project brings high added value, as it provides beneficiary countries with a structured opportunity to boost their development, share new methods for improved water management, improve planning at all levels of governance, and address unemployment and poverty.

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The REC is an international organisation with a mission to assist in addressing environmental issues. The REC fulfils this mission by promoting cooperation among governments, non-governmental organisations, businesses and other environmental stakeholders, and by supporting the free exchange of information and public participation in environmental decision making.

The WATER SUM project is financed by the Government of Sweden and implemented by the REC.
WATER SUM
Sustainable Use of Transboundary Water Resources and Water Security Management

WATER POR T
Water Resources Management Good Practices and Knowledge Transfer

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An introduction to the guide

Background

The project “Sustainable Use of Transboundary Water Resources and Water Security Management” (WATER SUM) was supported by the Government of Sweden through the Swedish International Development Cooperation Agency (Sida) and was implemented by the Regional Environmental Center for Central and Eastern Europe (REC) between April 2014 and March 2018.

The project focused on the Middle East and North Africa (MENA) region, through two main components: Component 1. Water Resources Management Good Practices and Knowledge Transfer (Water PORT); and Component 2. Water Security (WaSe).

The WATER PORT component aimed to promote and enhance the sustainable use of water resources in the MENA region. It offered a platform for facilitating dialogue, building skills and transferring knowledge on integrated water resources management (IWRM) and adaptation to climate change, working with water authorities at national level and with a broad selection of stakeholders. The component aimed to achieve the following results: (i) methodological capacity building and the reinforcement of the skills of respective national authorities; (ii) the promotion of a framework for common understanding among water practitioners and stakeholders; and (iii) strengthened abilities of practitioners to deal with the impacts of climate change on water resources.

In order to set out achievable and concrete objectives, WATER PORT proposes to focus on a few carefully selected major up- and downstream management issues related to IWRM: water demand management (WDM); water resources protection (WRP); and climate change impacts on water resources.

The environmental consultancy CIMERA was invited by the REC to provide support to WATER PORT activities in the field of capacity building on water resources protection in Jordan and Tunisia.

The objective of the assignment was to improve the skills and capacities of the respective authorities in Tunisia and Jordan for water resources protection. This included improving knowledge of the ecosystem aspects of watersheds; optimising monitoring networks; and introducing effective and efficient methodologies for monitoring, data management and exchange.

Introduction to monitoring

In terms of water management, water quality monitoring and control are key elements in establishing water uses within a country at different levels (national, regional and local).

Freshwater is a finite resource that is essential for human existence. Without knowledge of the characteristics of freshwater in relation to ensuring its adequate quantity and quality, the sustainable provision of safe drinking water will not be possible.

Water is affected by:

- changes in the climate, which increase evaporation and affect salinity rates, sedimentation, etc.; and
- human activities such as industrial and agricultural activities, the production of waste, and artificial recharge, which can affect water quality through the introduction of pollutants, including:
  - sediments from erosion/deposition;
  - nutrients from fertilisers and livestock breeding;
  - heat from industrial processes;
Purpose of the guidance document
The purpose of the present manual is to provide guidance on the common techniques, methods and standards that are used for sample collection, handling, quality assurance and control, custodianship, and data management. It is intended for use by local authorities, ministries, agencies, and any technicians potentially involved in water monitoring in the MENA region, with special attention to the regional characteristics in each watershed in Jordan and Tunisia.

Due to the variety of bodies and institutions in charge of water monitoring in each region, it is important that the same procedures for data exchange and trend analyses are followed, in order to provide comparable data.

The present manual is part of an integrated monitoring framework that assists in decision making in areas such as monitoring priorities, indicator selection, data handling, site definition and general procedures.

The manual outlines procedures for:

- sample design;
- sampling in the field:
  - making in situ tests and water quality measurements;
  - taking samples for water quality assessment, including samples of wastewater, surface water and groundwater; and
  - taking samples of sediments and biota;
- preserving and storing samples for water quality assessment, including samples of wastewater, environmental waters, sediments and biota;
- the security and transportation of samples;
- arranging laboratory analyses; and
- data analysis and interpretation.

In addition, in response to the needs of stakeholders, during the consultation period agreement was reached on the need to include in the annexes further specific material related to hydrological studies, encompassing:

- water balance;
- flow duration; and
- discharge calculation.

Scope of the guidance document
The content of the present document is mainly related to the monitoring process for surface water and groundwater. The monitoring process is described with reference to international protocols and recommendations. Recycled water, wastewater and water from desalination are not covered by the guide.

Technical advice is provided with respect to the design of monitoring programmes, site location, hydrological measures, parameters to be measured, sample preservation and quality control in laboratories, for example. The guide also contains ideas related to automatic systems for water monitoring and the use of different materials in the field.

This information will give users a general idea of the water monitoring process as a whole, and will provide a useful background for data processing and exchange and integrated water management agreements.

Target audience
The guidance manual is designed to help:

- water monitoring technicians to undertake monitoring programmes;
- water project leaders to manage the experts who undertake monitoring; and
- policy makers to use monitoring results in the policy-making process, to report results to the water authority, or to exchange results with other organisations or countries.

The MENA region
The MENA region is considered to be one of the most arid in the world, and, despite regional diversity, most MENA countries face water stress or water scarcity.

Water scarcity is one of the world’s biggest problems in the 21st century. Lack of water results in food shortages, creating vulnerability to hunger and poverty in regions where population growth is typically greater than capacities for the sustainable use of natural resources.

In terms of water scarcity and drought, the MENA region has the following characteristics:

- arid zones with limited precipitation, potentially affected by future climate change impacts — that is, increasing variability and extremes (in particular droughts), and resulting uncertainty in water availability;
- streams with temporary water flow, which have an economic impact on agriculture and food supply;
- the dominance of groundwater as a source of supply;
- water dependence, since water resources that cross national borders place the countries sharing the resource in a state of interdependence; and
- a regional dimension, since many issues related to water quantity and quality are typically dealt with at national or sub-national level.

The overarching water-related problem in the MENA region is thus water quantity, since water is a scarce resource. However, water quality is also emerging as an important issue, and one that is of growing concern to the public.

The main water challenges are therefore related to:

- providing sufficient quantities of safe water to larger segments of society;
- maximising the social and economic benefits of available resources through proper IWRM; and
- enforcing water laws and other water regulations.
In general, streams with a temporary flow are a challenge that has not been properly addressed in the context of water monitoring in some regions.

In Mediterranean areas and arid regions, the question of quantity is becoming relevant not only for the characterisation of the behaviour of water bodies in terms of status and risks, but also for a comprehensive definition of their quality status.

The specific hydrological variability of temporary streams also drives pollution dynamics, thus practical measures are required in relation to:
- the introduction of nutrients and organic matter from sewage effluents;
- debris, particulates and adsorbed nutrients due to erosion;
- hazardous substances in stream sediments; and
- integrated flood management.

Water management with respect to temporary streams, and the related monitoring, require consideration of the streams’ specific hydrological nature, the characteristic sequence of pollution accumulation and transportation during flood events, and the drying out of their channels due to natural and/or anthropogenic factors.

Groundwater is an essential resource for the region, especially for North African states that share two of the most important groundwater aquifers on the African continent. Monitoring risks related to overexploitation and salinity increase, among other things, is therefore crucial.

Institutions responsible for monitoring in Tunisia

Water quality and quantity monitoring systems are distributed among various institutions (see Table 1), and there is little contact or coordination among them. Nevertheless, an attempt is being made to coordinate the data collected by all these institutions through the implementation of the national water information system SINEAU, which comprises a coherent set of devices, processes and information flows through which water data are acquired, collected, organised, processed and made available. However, the system is not being fully used as there is a lack of capacity in terms of data use.

- L’Office National de l’Assainissement (ONAS) is in charge of wastewater treatment and reuse, and pumping stations for water distribution.
- L’Agence Nationale de Protection de l’Environnement (ANPE) is in charge of pollution protection and undertakes a general evaluation of environmental impacts in the water sector.
- La Direction Générale de la Qualité de la Vie (DGQV) is active in the fields of water evaluation and the protection of water quality against pollution.
- La Direction de l’Hydraulique Urbaine (DHU) is concerned with flood protection plans.
- Le Ministère de la Santé Publique (Ministry of Public Health) is concerned with water quality protection through its Direction de l’Hygiène des Milieux et de la Protection de l’Environnement (Directorate for Hygiene and Environmental Protection: DHMPE).

Institutions responsible for monitoring in Jordan

The water quality monitoring service is centralised under the Laboratories and Water Information and Quality Assurance Directorates of the Water Authority of Jordan. The water monitoring network in Jordan is generally considered to be large and complete. However, there are other institutions, such as the Royal Scientific Society, that also have laboratories and a water quality monitoring network that collects and makes available water quality data on the major surface water resources in Jordan (Table 2).

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Introduction

The large number of existing water databanks in Jordan has prompted an attempt to centralise all water quantity and quality data, with the aim of creating a national water information system.

With respect to data processing, it is generally agreed that capacities are lacking for handling, interpreting and assessing the quality of the vast amount of data gathered by the different institutions. A need to strengthen capacities was also expressed in other areas of water and water quality assessment systems. A main reason for this need for capacity building is apparently the high internal turnover in the administration.

Legal responsibilities with regard to water resources monitoring and planning lie with the Ministry of Water and Irrigation (MWI), the Water Authority of Jordan (WAJ) and the Jordan Valley Authority (JVA). The Jordanian Institute of Standards and Metrology is responsible for issuing standard specifications for the water sector in cooperation with representatives of the MWI, WAJ and JVA, as well as representatives of the Ministry of Health and the Ministry of Environment.

The importance of water quantity and quality

The composition of surface water and groundwater is dependent on natural factors (geological, topographical, meteorological, hydrological and biological) in the drainage basin and varies with seasonal differences in runoff volumes, weather conditions and water levels.

Continental water bodies are of various types, including streams, lakes, reservoirs and groundwater. All of them are inter-connected by the hydrological cycle with many intermediate water bodies, both natural and artificial, such as wetlands (floodplains, marshes) or alluvial aquifers, which have characteristics that are hydrologically intermediate between those of rivers, lakes and groundwater.

Characteristics of groundwater

Groundwater is held in the pore space of sediments such as sand or gravel, or in the fissures of fractured rocks such as crystalline rock and limestone. The body of rock or sediments containing the water is called an aquifer, and the upper water level in the saturated body is referred to as the water table.

Typically, groundwater has a steady flow pattern. Velocity is governed mainly by the porosity and permeability of the material through which the water flows, and it is often up to several orders of magnitude less than that of surface waters. As a result, mixing is poor.

Aquifers may be confined or unconfined. A confined aquifer is covered by an impermeable layer that prevents recharge (and contamination) by rainfall or surface water. The recharge of confined aquifers occurs where the permeable rock outcrops at or near the surface, which may be some distance from the area of exploitation. This feature may make it more difficult to control quality and pollution. Some aquifers are not perfectly confined and are termed semi-confined or leaky.

The quality of groundwater depends on the composition of the recharge water; the interactions between the water and the soil, soil-gas and rocks with which it comes into contact in the unsaturated zone; the residence time; and the reactions that take place within the aquifer. Considerable variations can therefore be found, even in the same general area, especially where there are rocks of different composition and solubility. The principal processes influencing water quality in aquifers are physical (dispersion/dilution, filtration and gas movement), geochemical (complexation, acid–base reactions, oxidation-reduction, precipitation-solution, and adsorption-desorption) and biochemical (microbial respiration and decay, cell synthesis).

Groundwater quality is affected by the impacts of human activities that cause pollution on the land surface, since most groundwater originates from recharge by rainfall infiltrating from the surface. The rainwater itself may also have increased acidity due to human activity. The unsaturated zone can help to reduce concentrations of some pollutants entering the groundwater (especially micro-organisms), but it can also act as a store for significant quantities of pollutants such as nitrates, which may also be eventually released from this zone. Some contaminants enter the groundwater directly from abandoned wells, mines and quarries and from buried sewerge pipes that by-pass the unsaturated zone (and, therefore, the possibility of some natural decontamination processes).

In groundwater monitoring, the level of water, the quality of the sample and physico-chemical parameters are crucial for classifying the status of the waterbody.

Characteristics of surface waters

Continental surface water can be divided into rivers, lakes and wetlands. There are also artificial water bodies, such as canals, ponds and reservoirs, that should be included in the monitoring network.

Rivers have a unidirectional flow, often with good lateral and vertical mixing. An understanding of the discharge regime of a river is vital for the interpretation of water quality measurements, especially those including suspended sediment or intended to determine the flux of sediment or

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contaminants. The discharge of a river is related to the nature of its catchment, and particularly the geological, geographical and climatological influences.

In the case of lakes and reservoirs, one important factor affecting water quality is stratification, which occurs when the water in a lake or reservoir acts as two different bodies with different densities, one floating on the other. It is most commonly caused by temperature differences, leading to differences in density (water has maximum density at 4°C), but occasionally by differences in solute concentrations. The quality of the water in the two different bodies is also subject to different influences. The surface layer, for example, receives more sunlight while the lower layer is physiologically separated from the atmosphere (which is a source of gases such as oxygen) and may be in contact with decomposing sediments, which exert an oxygen demand. As a result of these influences, it is common for the lower layer to have a significantly decreased oxygen concentration compared with the upper layer. When anoxic conditions occur in bottom sediments, various compounds may increase in interstitial waters (through dissolution or reduction) and diffuse from the sediments into the lower water layer. Substances produced in this way include ammonia, nitrate, phosphate, sulphide, silicate, iron and manganese compounds.

All of these characteristics should be taken into account when designing the monitoring of lakes and reservoirs. In reservoirs located in temperate areas, as in the MENA region, thermal stratification occurs during warm seasons, which generates layers of water with different qualities, depending on the depth, as a result of the vertical heterogeneity. Eutrophication (nutrient enrichment), which is experienced in most reservoirs, lakes or swamps, often causes serious water quality problems, increasing primary production and favouring cyanobacterial blooms that harm water quality and can cause health problems when associated with toxin production. When the reservoir is stratified, primary production is concentrated in the surface layers, preventing light from entering the deeper layers. At the end of the biomass life cycle, this large amount of biomass falls to the bottom and oxygen is consumed for its degradation, causing oxygen exhaustion as there is no possibility of exchange with the upper layers. The lack of oxygen drives degradation through anaerobic pathways, which results in the accumulation of toxic chemicals such as hydrogen sulphide or ammonia, and also the production of greenhouse gases such as methane. In cold seasons, however, the waterbody is homogenised and there is a respective change in quality conditions.

The monitoring of surface water should include at least physico-chemical parameters in situ, chemical analysis in the laboratory, and biological sampling in order to classify the status of the waterbody.

Characteristics of wastewater

Wastewater is any water that has been adversely affected in quality by anthropogenic influence. Wastewater can originate from a combination of domestic, industrial, commercial or agricultural activities, surface runoff or storm water, and from sewage inflow or infiltration.

Wastewater monitoring related to environmental aspects should be aimed mainly at providing data for pollution control and protection. The measurement of wastewater discharges containing nutrients may be part of the monitoring programme in urban areas.

Elements of a water quantity monitoring programme

As in the design of a water quality monitoring programme, it is important to clearly define the purpose of the water quantity monitoring programme, what information is needed and what information is already available, in order to identify the gaps that need to be filled.

When defining the aims, it is always a priority to prepare a monitoring roadmap. A hydrological monitoring roadmap describes in greater detail the goals to be achieved, any possible limitations, and the materials and devices to be used.

A monitoring programme typically comprises the elements shown in Figure 1, which are further defined in this guidance document.
Designing a monitoring programme

The design of a monitoring programme should be based on clear and well-thought-out aims and objectives, and should ensure, as far as possible, that the planned monitoring activities are practicable and that the objectives of the programme will be met.

When designing monitoring programmes, it is important to ensure that the sampling regime and the parameters are representative of the water system to be characterised. Using appropriate methods and quality assurance measures is key to ensuring that the field sites selected and the samples collected accurately represent the environment intended for study and fulfill data quality objectives.

The essential features of a sampling strategy are to ensure that the material sampled is genuinely representative of the body of material from which it was collected, that in situ measurements are reliable, and that the integrity of materials sent for laboratory analysis has not been compromised by contamination, degradation, transformation or losses.

The principal elements of a study plan are:
- a clear statement of aims and objectives;
- information expectations and intended uses;
- a description of the study area concerned;
- a description of the sampling sites;
- the standard of the water quality variables that will be measured;
- the proposed frequency and timing of sampling; and
- an estimate of the resources required to implement the design, and a plan for quality control and quality assurance.

The purpose of monitoring

The principal reason for monitoring is the need to verify whether observed water quality or quantity are suitable for intended uses. This can be done through assessments of current water quantity and quality related to its variability in space and time.

Such assessments typically include appraisals of the hydrological, morphological, physico-chemical, biological and/or microbiological conditions compared to reference conditions, impacts on human health, and/or the existing or planned uses of water (see Figure 2).

The design process must begin with the end in mind. Dams or diversions located upstream or downstream are both useful, although for very different purposes. An upstream area will represent a compilation of all runoff processes occurring in the contributing watershed, whereas a downstream area comprises all information about what will be happening in receiving aquatic and riparian ecosystems. A good location is one where the variation in discharge is sensitive to the phenomena of interest.

The goals of the monitoring programme will determine which parameters need to be included in the network design. If the objective is regulatory compliance or the development of statistics for engineering design, then perhaps the only parameter needed is discharge. However, if the purpose is to understand runoff processes, to develop water management policies, or to calibrate predictive models, then network design should consider all relevant components of the water cycle, including stores (e.g. groundwater, snowpack and lake levels) and flux (e.g. temperature, evaporation and precipitation). The measurement of some parameters (e.g. sediment and water quality) must be located with discharge gauging if loadings are a requirement.

A monitoring programme may be designed for either management purposes, or assessment purposes.

Monitoring for management

The programme will sometimes yield data and information that will be of value for management decision making. The critical element is the development of objectives. These objectives can be divided into long-term objectives (such as integrated monitoring for environmental and health protection) or short-term objectives (such as monitoring for immediate health priorities). Water quality standards may be laid down by national legislation. A government authority is then charged with monitoring the extent to which the standards are fulfilled.

Monitoring for assessment

Some monitoring provides information that is required and essential for an assessment of water quality or quantity and watershed management. However, assessments require additional information, such as an understanding of the hydro-dynamics of a waterbody; information on geochemical, atmospheric and anthropogenic influences; and the correct approaches for the analysis and interpretation of the data generated during monitoring.

Monitoring for assessment involves sampling that can be undertaken for a range of reasons, including:
- investigating pollution incidents to discover and prove the nature, source and effects of the contaminant;
- confirming compliance to the licence conditions of an environmental authority or development approvals;
- undertaking an environmental monitoring programme for water protection; or
- undertaking the environmental evaluation of an activity.

In general, the objective of the monitoring process is to obtain a representative sample of the material being studied (watercourse, industrial effluent, wastewater etc.), thus physico-chemical variables must be analysed. The captured material is transported to a storage location (cold room, refrigerator etc.) and then transferred to the laboratory for the respective analyses, during

FIGURE 2 Elements to include as part of a possible monitoring programme
Designing a monitoring programme

which the sample must retain the characteristics of the original material. This requires that the sample retain the relative concentrations of all components present in the original material, and that no significant changes occur in its composition before analysis.

In some cases, the purpose of sampling is to demonstrate that the standards specified by law are being met. The techniques for collecting and preserving samples are very important, because of the need to verify the accuracy, correctness and representativeness of the data obtained from the analysis.

Site selection and field campaign preparation

Proper preparation before going to the field is critical in order to ensure a successful field sampling campaign, and the safety and well-being of the field team. Prior to any field campaign, it is important to have a good understanding of the area to be surveyed, including its topography, climate and vegetation characteristics, accessibility, and security situation.

Study of information from previous surveys

The first step in monitoring design should be the gathering of background information. Information concerning the history of the activity (e.g. water data, industrial activity, floods, droughts, algae blooms, historical spills) can be extremely useful when planning sampling events.

Part of the design phase should be spent collecting existing data from the area and organising materials and technicians for the work. It is crucial to use previous information on the area in order to analyse the important causes of pressures, impacts, risks etc. in the watershed, making it possible to define the monitoring network and analyse the subsequent results. It is also important to collate existing information about the area to be surveyed, including maps (topographical, geological, soils and/or vegetation), satellite images and/or historical aerial photographs, long-term weather station data, government statistics, census data etc. For water quality analysis, any evidence of previous flood events, deforestation or drought indications are extremely important. Such evidence is also linked to water quality, as it may explain certain quality information. The coordinates of sampling locations should be uploaded to GPS units before going to the field. If possible, local maps should also be loaded to aid navigation in the field.

A file search may provide guidance in choosing which parameters to include for analysis. Additionally, when no information is available, field personnel must consider that worst case conditions may exist and must take proper precautions to ensure safety.

Just as important as finding out what may be on site is determining where it is most likely to be located. A pre-sampling site visit should therefore be conducted to gather additional background information.

Preparation for the fieldwork

When conducting field campaigns in new areas, it is generally recommended to undertake a reconnaissance survey, during which local contacts are established and agreements made. A thorough equipment check is essential before leaving for the field.

Where necessary, permission must be obtained from the local authorities to take samples from a given area, and local government officials and community leaders should be informed about sampling activities. During the preparation phase, it is a good idea to agree with data collection colleagues on the format of the datasheets to be used in the field, and also on the type of information to be collected, and the purpose for which it will be used. Prior to the field visit, areas where data are lacking, or where inconsistency between data (historical data, remarks, bibliography etc.) could lead to misunderstanding, should be addressed.

Selecting sampling sites

Sampling must be done at properly selected sites so as to obtain the most reliable data. Good field practice provides the basis for the processing of laboratory sampling and result interpretation.

The first step in any monitoring is to determine the objectives and purpose of the monitoring.

Once the monitoring objectives and criteria for geophysical representativeness are established, a specific reach of river can be selected for monitoring. A desirable location is one with uniform, gradually varying flow; inexpensive site access; stable geophysical features for vertical control benchmarks and for channel control; and safe stream gauging conditions.

Monitoring objectives are often restricted because of adverse monitoring conditions in particular locations. A mismatch between local conditions and appropriate technology results in poor-quality data and high maintenance requirements for both field and office procedures. Nowadays, it is possible to accommodate almost any compromise needed in terms of site selection. However, the most reliable and affordable solutions are predicated on good site selection.

Site selection affects the following outcomes:

- data persistence (i.e. a well-selected location should produce data for generations to come);
- data quality;
- data representativeness;
- operational costs;
- liability risks;
- the selection of methods; and
- reliability risks.

As a best practice, network design should be an ongoing process and those involved should be prepared to make wise choices at short notice.

This chapter provides guidance on how to select appropriate sampling sites in streams and rivers; how to select sampling sites in lakes and reservoirs; and how to select sampling sites for the monitoring of groundwater.

Selecting appropriate sampling sites in streams and rivers

When designing and defining the monitoring area, the area for sampling should have certain characteristics, as outlined below.

A 100-metre reach that is representative of stream characteristics should be selected. Whenever possible, the area should be at least 100 metres upstream from any road or bridge crossing the stream in order to minimise impacts on stream velocity and depth, and overall habitat quality. There should be no major tributaries discharging into the river or stream in the study area. Sampling should begin at the downstream end of the reach and proceed upstream.

A map of the sampling reach should be drawn, including in-stream attributes (e.g. bottom area geology, habitats), important structures (e.g. bridges, roads, marginal protection), vegetation, and the attributes of the banks and near-stream areas. The direction of flow should be indicated with an arrow. If available, a hand-held global positioning system (GPS) should be used to determine latitude and longitude, taken at the furthest downstream point of the sampling reach.

It is important to define the location of the sampling sites before going into the field, and this should form part of the desktop work carried out in the planning process. When selecting and defining a location (sites or stations), a hand-held GPS can be a useful way to quickly record the location of sampling sites, by storing them as waypoints.
A map-based evaluation of each site is required prior to going into the field. If available, site photographs can also be helpful. A (digital) map of the investigated stream or river reach should preferably be used, with a scale of 1:10,000. If not available, scales of 1:25,000 or 1:50,000 are also acceptable. The finally selected sampling site(s) must be representative of the evaluated waterbody (habitat structure) and watershed (characteristics of the surrounding land), and must be relevant to the objectives defined by the project. In lotic waterbodies, sampling in rapidly flowing, safely wadeable riffle sections is recommended.

The final selection of representative sampling sites must be done in the field. Pre-sampling site evaluation involves reviewing the information on point sources of pollution, as well as general topographical and site access information. The type and order of the lotic system should be specified. If required, access to the sampling location and permission to sample should be obtained in advance from landowners.

When selecting sites for biological sampling (macroinvertebrates), all riffle and run areas within the 100-metre reach are candidates for sampling. A composite sample is taken from individual sampling spots in the riffles and runs representing different velocities.

At pre-selected sites, the overall suitability for sampling should first be assessed by walking along the banks to evaluate where to start sampling. Before the fieldwork starts, it is important to agree with the physico-chemical expert and the hydromorphologist to take samples from different areas in close proximity, so as not to affect each other’s work.

Once the river area is selected, the river stretch should be divided into different areas according to the different substrates present, and the proportion of each type should be estimated when sampling for biological elements. Thus, if an estimated 30 percent of the river area has a high current velocity and hard substrate, 60 percent is covered by submerged macrophytes, and 10 percent is bare gravel, then the same proportions should be used for sub-sampling the different habitat types.

**Selecting sampling sites in lakes and reservoirs**

The selection of sampling sites depends on the specific monitoring objectives. If the objective is to assess general water quality, one site could be sufficient. If the monitoring purpose focuses on a particular problem, it may be necessary to add additional sites for monitoring.

The size and shape of the lake or reservoir are crucial for site determination. These are usually the most influential factors when determining the number and location of sites. It is necessary to check lake arms, possible spills or towns that could influence the sampling process. It is important to avoid sampling near the shore, near inflows, or in downwind areas. In this kind of waterbody, it is also important to decide the depth at which to collect water samples.

**Selecting sampling sites for monitoring groundwater**

Existing wells and piezometers in the study area largely define the potential sites for groundwater sampling. However, natural features (such as springs) or artificial features (such as mine shafts or pits) can also be used for groundwater access. It is common practice to take samples from surface waterbodies and rainfall for integration with the groundwater chemistry.

Where groundwater wells are used, the following criteria should be borne in mind:

- Spatial and depth distribution, to allow reasonable representation across and within target aquifer(s).
- Spatial distribution, to allow the development of cross-sections parallel and perpendicular to regional groundwater flow paths.
- The depth to water level, ranging from shallow to deep groundwater systems (including perched and multiple aquifers). Some nested or multi-stemmed piezometers may need to be used for sampling, in order to investigate chemical variations with depth at a site.

- The representativeness of the various land uses, irrigation practices, and industrial or urban areas. Sampling needs to be carried out to address the groundwater contamination potential, with particular reference to nutrients, pathogens and pesticides.
- The representativeness of the recharge, and the nature and extent of groundwater/surface water interaction.
- The representativeness of the diversity of groundwater use in the area, including irrigation, stock, domestic and town water supply, and logistical issues that define well accessibility, operating conditions, road access and the existence and nature of bore equipment (such as installed pumps).

**Frequency and timing of sampling**

The schedule for the sampling programme should take into account the temporal resolution of changes in the environment. In programmes for monitoring wastewater treatment effluents, sampling around the clock may be required to determine whether control variables have been met or exceeded. A single sample can only be a snapshot at a single point in time and may not reliably represent typical conditions for a system that varies over time.

**Groundwater**

Monitoring frequency should make possible the assessment of the quantitative and chemical status of groundwater bodies. As a minimum, surveillance monitoring should be carried out once per planning period. Monitoring frequency should generally be based on the characteristics of the aquifer and human impacts.

In reference monitoring wells and/or springs, it is advisable to collect groundwater samples at least four times a year in order to determine seasonal fluctuations in groundwater chemistry. Later, if analytical results show no significant variations, the sampling frequency can be reduced, although it is recommended to undertake no fewer than two sampling rounds a year.

In situations where funding is not sufficient, groundwater quality may be monitored using the principle of rotation: water sampling is more frequent in vulnerable aquifers (unconfined, and with high human load), and less frequent in naturally protected, confined aquifers. With respect to indicators, chemical components such as pesticides or metals with generally very low concentrations can be monitored once every two to six years in wells where these components are likely to be detected.

**Surface water**

Water quantity is an important variable to overview periodically when assessing water quality status. A measuring campaign should assess the river monitoring network at different levels. In the event of floods, monitoring should be carried out as soon as possible in order to better analyse patterns.

Since water quality varies with stream flow conditions, when determining the timing of sampling it is important to establish whether sampling carried out during base flow or during flood events (or both) is more appropriate.

For the assessment of water quantity, both conditions (base flow and flood events), water scarcity and ecological flow may be relevant, and can lead to better understanding of the hydrological nature of the watershed.

Sampling frequency is also an important factor in terms of representativeness. Low sampling frequency could result in an underestimation of the occasional presence of high analyte concentrations.
It is also necessary to define the best season for sampling biological elements. Macro-invertebrate sampling for status assessment is usually undertaken in the spring and autumn of the same year, as communities’ peak abundance and diversity occur in spring and/or autumn. It is possible to take samples at other times of the year, or in only one of the two seasons mentioned (e.g. if high flows make sampling unsafe), although seasonal sampling is intended to both minimise the effect of seasonality (as it provides knowledge of the same location at different times of the year) and increase certainty/confidence in the results. Sampling frequency in the case of phytoplankton may be every six months to one year, although this will be adjusted in each specific case to the conditions in the reservoir or lake. Samples could be taken from the surface water (every month) or from the column of water to check the evolution of the community during the different phases of stratification and mixing, depending on the purpose of the analysis.

Sampling methods
All the procedures for sampling are included in international standards, where the general principles for guidance are set out:

- The design of sampling programmes and sampling techniques for all aspects of water sampling, the establishment of the general requirements for sampling; and the preservation, handling, transportation and storage of all water samples, including those for biological analyses.
- Guidelines for the design of sampling programmes and techniques and the handling and preservation of water samples from natural and artificial lakes during open-water and ice-cover conditions. These are applicable in lakes with and without aquatic vegetation.
- Guidance on the sampling of groundwater, which inform users of the necessary considerations when planning and undertaking groundwater sampling to survey the quality of groundwater supply, to detect and assess groundwater contamination, and to assist in groundwater resource management, protection and remediation. The guidance includes the sampling of groundwater from both the saturated zone (below the water table) and the unsaturated zone (above the water table).
- The design of sampling programmes and sampling techniques, and the handling of water samples from rivers and streams for physical and chemical assessment.

In Tunisia, further information can be found on the website of the National Institute of Standardisation and Industrial Property, which operates under the Ministry of Industry, Energy and Small and Medium-Sized Enterprises: www.innorpi.tn (Figure 3).

In Jordan, further information can be found on the website of the Standards and Metrology Organisation: www.jsmo.gov.jo/en/Pages/default.aspx (Figure 4).

Groundwater sampling
It is recommended to introduce and follow standardised procedures for groundwater quality sampling. Until national sampling protocols are developed and approved, we recommend using the sampling procedures described in ISO 5667-11:2009, which establishes the principles for groundwater sampling (equipment, procedures, safety precautions etc.), focusing on surveys of groundwater quality to detect and assess groundwater pollution and to assist in groundwater resource management. In addition, ISO 5667-18:2001 describes the principles of groundwater sampling methods at contaminated sites, where monitoring wells must be appropriately purged before samples are taken.

General information on the choice of materials for sampling equipment can be found in ISO 5667-11:2009. In general, polyethylene, polypropylene, polyvinyl and glass containers are recommended for most sampling situations. Opaque sample containers should be used if the sampled parameter degrades in light (e.g. some pesticides). The contamination or modification of the chemistry of groundwater samples should be minimised by selecting suitable materials for sampling equipment and borehole construction.
Surface water sampling
It is recommended to follow the standardised procedures below when sampling surface water:
- ISO 5667-3:2012 Water quality – Sampling – Part 3: The preservation and handling of water samples
- EN 14614:2004 Water quality – Guidance standard for assessing the hydromorphological features of rivers
- EN 16039:2011 Water quality – Guidance standard on assessing the hydromorphological features of lakes
- Standards for physico-chemical parameters: Any relevant CEN/ISO standards.

Sampling of biological elements
When taking samples of biological elements (macroinvertebrates, phytoplankton, phytobenthos, fish, macrophytes), it is recommended to follow standardised procedures until national sampling protocols have been developed and approved. The recommended sampling procedures are described in the documents below.

GENERAL DOCUMENTS
EN 14996:2006 Water quality – Guidance on assuring the quality of biological and ecological assessments in the aquatic environment

MACROINVERTEBRATES
- UNE – EN 16150:2012 Water quality – Guidance on pro-rata multi-habitat sampling of benthic macroinvertebrates from wadeable rivers
- EN 15196:2006 Water quality – Guidance on the sampling and processing of the pupal exuviae of Chironomidae (order Diptera) for ecological assessment

Microbiological quality sampling
The evaluation of the microbiological quality of drinking water aims to protect consumers from illness caused by the consumption of water that may contain pathogens such as bacteria, viruses and protozoa. The water sampling procedure for microbiology is explained below.

1. SAMPLE BOTTLES
- Sampling bottles are defined by the laboratory.
- Pre-sterilised sampling bottles should have a capacity of at least 100 to 500 ml and be made of pre-sterilised disposable, autoclavable plastic.
- Prior to sampling, all bottles should be checked for physical defects.

2. DECHLORINATION
- 1 percent of 0.1 ml sodium thiosulphate under aseptic conditions is added to sampling bottles at the time of sampling for de-chlorination purposes. Sodium thiosulphate neutralises any residual chlorine and prevents the continuation of bactericidal action during sample transit.
Designing a monitoring programme

3. PREVENTING CONTAMINATION

Contamination must be avoided during the sampling procedure as 92 percent of errors arise from sampling, 7 percent from inappropriate sample transportation, and 1 percent from laboratory practices. The following points should be considered in order to avoid contamination during sampling:

- sampling points often introduce contamination, thus disinfection or flushing may be required in order to obtain a representative sample;
- the neck of the bottle and the inside of the lid should never be touched; when filling the bottle, the lid should not be placed on any surface, but held in the hand;
- the sample bottle should not be rinsed out prior to filling;
- the flow rate of the tap should not be changed during sampling as this may dislodge bacterial films inside the tap;
- a small air gap should be left in the bottle;
- once the bottle has been filled and the lid replaced, the sample should be placed in an icebox for transfer to the laboratory/testing point in field; and
- if accidental contamination is suspected, then the sample should be discarded and a new sample taken using a fresh container.

4. SAMPLING PROCEDURE

- Step 1: Spray spirit on hands for disinfection purposes.
- Step 2: Remove any attachments from the tap such as pipes, filters etc. Turn the tap on for five minutes to flush out the standing water, turn off the tap and clean with tissue paper. Spray a small quantity of spirit on the surface of the tap, ignite it with a match and let it cool.
- Step 3: After flaming, turn on the tap again until the water runs in a thin stream (about the width of a pencil), and let it run for one minute.
- Step 4: To avoid contamination while taking the sample, hold the bottle near the bottom with one hand, hold the top of the lid with the other hand, then unscrew the lid. Do not place the lid on the ground. Sampling will be more reliable if carried out near flame.
- Step 5: Hold the bottle under the stream of water, being careful not to let the bottle touch the sample tap. Fill the bottle to the neck, leaving a space of 2.5 cm from the top. Do not allow the bottle to overflow. Remove the bottle from the water flow and replace the lid.
- Step 6: Label the bottle with a permanent marker and keep it in an insulated icebox with sterilised coolants (under a controlled condition of 4°C). Samples should be delivered to the laboratory as quickly as possible.

Resources for a monitoring programme

Implementing a monitoring programme requires access to resources, including an equipped laboratory, office space, equipment for fieldwork, means of transportation and trained personnel.

Two important points should be considered when starting a new monitoring programme:

- It is better to have a complete record of reliable data concerning water quality at a few sampling stations than to have a lot of data of questionable quality from many sampling stations.
- If reported data are not credible, the programme and its staff will lose credibility.

In the initial stages of a new monitoring programme, it is therefore generally advisable to follow the guidelines below:

- start slowly, with the analysis of a few variables;
- undertake desk research to determine better areas for performing further analyses;
- train staff to ensure that proper procedures are followed;
- undertake quality assurance of all procedures from the very beginning;
- take samples at stations where water quality is of major relevance to the monitoring programme;
- prepare reports that are factual and that are written in such a way that they can be understood by persons other than scientists; and
- increase the number of variables, the number of sampling stations and the frequency of sampling.

Laboratory facilities

Ideally, a laboratory infrastructure should be established that will make it possible for all samples to be transferred to a central or regional laboratory within a few hours of being taken. However, this depends on the availability of a good road system and of reliable motorised means of transportation for all sampling officers, which is not always the case in many countries. Thus, although it may be possible to establish well-equipped central and even regional laboratories for water analysis, at the provincial and district levels it may be necessary to rely on a relatively small number of simple tests.

Wherever possible, for the specific analysis of contaminants it is recommended to contact the appropriate laboratories before going to the field, to ensure that analysis can be performed before the expiry of the maximum holding times. Laboratory analysis of priority substances in the sediment, for example, requires sophisticated analytical equipment and methods, while concentration levels can be analysed with existing techniques.

In the case of biological samples, a group of experts must be involved in identification: a taxonomy specialist should examine and analyse the sample taken in the field. Organisms should be examined with a hard lens to determine their identity (at the lowest possible level).

Transport

Samples collected in areas remote from the laboratory might need to be freighted by private companies — whether by road or air — if they cannot be delivered in person. The samples must be delivered within the maximum holding times.

Even in developing countries that are poorly served in terms of roads and transportation, it is usually possible to devise a rational sampling and analytical strategy. This should incorporate carefully selected critical parameter tests in remote (usually rural) locations using simple methods and portable water-testing equipment where appropriate.
In the case of biological monitoring, the samples should be transported to the laboratory and stored for no longer than three to six months without review.

Human resources development and training
The present guide is part of a comprehensive training, comprising theoretical documents, theoretical training and field training in different locations in the countries.

Key questions with respect to human capacities include:

- Do we have sufficient staff?
- Are our staff members skilled in standardised water monitoring procedures and the assessment of the status of waterbodies?

The number of staff members involved is typically linked mainly to the budgets that are available for the various monitoring activities (including salaries). However, staffing issues are not limited to financial issues alone. The monitoring of water quality in a country implies that the monitoring of biological and hydromorphological quality elements has become a regulatory necessity. This involves several new parameters and new assessment methods.

Related to this quality monitoring and assessment approach, many topics — such as the analysis of priority substances, assessments based on type-specific reference conditions and ecological quality, quantitative assessments of groundwater, and several hydromorphological parameters — will require new skills on the part of the national professionals involved in the monitoring strategies.

Schedules for sampling expeditions
Once the sampling design has been finalised, a sampling schedule should be prepared that includes such information as:

- where and when the samples are to be collected;
- the source of each sample — whether from waste, water or sediments;
- the nature of the material to be sampled;
- the quality characteristics being sampled;
- the identification of the different elements to be analysed;
- the sampling containers (and associated equipment) required;
- the necessary preservatives; and
- the maximum holding time for each sample.

Fieldwork and sampling
Sampling expeditions should be planned and carried out in such a way that efforts are not wasted. If, for example, an essential piece of equipment is forgotten, or an inadequately described sampling station cannot be found, the value of that particular sampling expedition is seriously compromised. Similarly, if unrealistic estimates of travel time are made and an expedition takes longer than intended, samples may be held longer than the maximum allowable storage time and the results of the analyses will be of questionable value.

Materials for sampling

Personal protection
Personal protective equipment includes:

- boots or fishing waders;
- latex gloves; and
- safety vest.

For groundwater sampling
The device used to purge a well and take samples depends on the diameter of the inner casing, the depth to water, the volume of water in the well, the accessibility of the well, and the types of contaminants to be sampled. The types of equipment available for groundwater sampling include hand-operated or motor-driven suction pumps, peristaltic pumps, positive displacement pumps, submersible pumps, various in situ devices and bailers made of various materials, such as PVC, stainless steel and Teflon®. Additional elements include isokinetic samplers, sample tubing, semipermeable membrane devices (SPMDs), filtration devices, churn splitters, cone splitters, bottles and water (deionised water, tapwater, blanks).

For surface water sampling
The following equipment is required:

- multimetric probes for physico-chemical monitoring;
- probes for the hand monitoring of surface water;
- real-time multiparameter water quality sondes for surface water;
- water-quality field kits (basic physico-chemical parameters) (Table 3);
- self-recording current meter (h = 1 m) for direct reading of water speed;
- limnograph for the continuous automatic registration of water level;
- an M-scope groundwater level indicator;
- bottles;
- samplers;
- coolers;
- preservatives; and
- kits for in situ measurements.

### TABLE 3 Basic in situ physico-chemical parameters

<table>
<thead>
<tr>
<th>Physico-chemical</th>
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<td>Electrical conductivity (EC)</td>
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<tr>
<td>Temperature</td>
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<tr>
<td>Redox potential (ORP)</td>
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<tr>
<td>Dissolved oxygen (DO)</td>
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<tr>
<td>Turbidity (NTU)</td>
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<tr>
<td>Total dissolved solids (TDS)</td>
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Fieldwork and sampling

For macroinvertebrates
The following equipment is required:
- GPS;
- map;
- camera;
- antibacterial liquid (soap);
- life jackets (if relevant);
- hand net sampler (500 μm, rectangular frame: 0.25 x 0.25 m or 0.3 x 0.3 m);
- a naturalist’s dredge with a rope;
- bucket;
- set of three sieves (diameter 20 cm);
- sample containers/jars (1,000 ml in volume);
- white trays;
- fixation and conservation compounds;
- plastic spoons;
- permanent markers;
- sampling field protocol for macroinvertebrates;
- field magnifying glass;
- waterproof chest waders and waist belt;
- labelling tape;
- metre ruler;
- stopwatch;
- gloves; and
- field meters (pH, dissolved oxygen, temperature, electrical conductivity).

For phytoplankton
The following equipment is required:
- transparent glass bottles or rigid plastic containers (with a volume of 250 ml for phytoplankton);
- glass vials or plastic sealing plugs (for phytoplankton networks);
- opaque plastic bottles (2 l) (for chlorophyll);  
- water bottles (for discrete samples at depth);
- hose ballasting of predetermined length (for integrated samples);
- Nytal mesh with 0.35 mm pore size (for trawl samples);
- a Secchi disk;
- fluorometer (optional); and
- GPS.

Although it is recommended always to collect samples directly into the appropriate bottle or jar, it may sometimes be necessary to use an intermediate container to collect samples, such as buckets, beaters, pumps, filters, syringes, sediment grabs, trowels and/or sampling rods.

A sampling pole with a large clamp (or other suitable device) to hold the sampling container can be used to give greater reach when collecting samples.

In some circumstances, it may be preferable to use an automated sampling device to collect samples. Sampling using automatic systems can be carried out over a defined period of time and for different kinds of samples (e.g. simple or composed), and the samples can be refrigerated and preserved. Automatic samplers include remote samplers, such as rising-stage and falling-stage samplers.

For some analyses, samples must be filtered in the field before they are placed in the container used for transportation to the laboratory.

In the case of water, waste and bottom sediment sampling, each sample should be collected and stored in a container appropriate for the quality characteristics being investigated. Appropriate containers and preservation methods are necessary in order to prevent the risk of sample contamination and/or losses of analytes of interest during storage and transit prior to analysis.

Sampling procedures

Groundwater sampling
Groundwater sampling requires special equipment for taking samples from boreholes or wells (e.g. a suitable bailer or pump), and a procedure to ensure the sampling of fresh recharge water from the aquifer. Special precautions are sometimes needed to prevent changes in the quality of the groundwater due, for example, to:
- reduced pressure when the water is brought to the surface, which can cause the evolution of gases that are found in solution at the higher pressures underground — in some cases, these can be toxic gases, such as hydrogen cyanide, if the groundwater has been contaminated by cyanide solution; or
- exposure to components in the atmosphere such as oxygen, which can result in the oxidation of compounds naturally present in the reduced form (e.g. ferrous iron).

The collection of groundwater samples requires specialised knowledge. The sampling of groundwater for microbiological examination requires the normal precautions mentioned above, plus precautions for preventing microbial contamination of the sampling equipment and the precautions applicable to surface water sampling. If such samples need to be collected, advice should be obtained from reliable sources.

The groundwater sampling procedure begins with preparations in the office before sample collection. Field tests normally comprise pH, redox potential (Eh), temperature, specific conductance, alkalinity, dissolved oxygen and other parameters, tailored to each aquifer. Before sampling, the well must first be purged to remove the stagnant water from the well casing. The amount of water that should be pumped before the collection of water samples depends on the volume of water in the well casing. It is generally agreed that a minimum of two to three casing volumes of water should be pumped out and/or the pH, temperature and electrical conductivity of the discharging water should be stabilised. Measurements of water temperature, pH and conductivity are made while the well is purged. Measurements are repeated at five-minute intervals until the parameters equilibrate. When pH readings are within ±0.1, it is an indication that water parameters have stabilised.

In polluted aquifers, it is strongly recommended to use dedicated purging equipment for each monitoring well. If dedicated purging equipment (bailer or pump) is not used, then the equipment must be properly cleaned before sampling another well. On returning to the office or laboratory, all field monitoring equipment must be cleaned and inspected.
A borehole that is pumped or bailed dry with the sampling equipment should be allowed to recover prior to sampling. When sampling groundwater monitoring wells or boreholes, the purge water must be disposed of in accordance with environmental requirements and regulations.

NORMALLY, purge water from clean wells is discharged onto the ground surface, and water from polluted boreholes is collected and transported to a treatment facility. When sampling in drinking water areas, water quality samples should be taken at all significant groundwater abstraction points associated with drinking water protected areas and from groundwater bodies that are at risk from diffuse or point sources of pollution. Water quality samples should be taken at least once in each river basin management cycle and analysed for all chemical parameters required by national legislation.

**Surface water**

Surface water can be sampled using manual procedures or automatic systems. There is a traditional sampling process method that consists of taking samples and doing in situ measurements at different stations in order to monitor trends in water quality. These samples may be sent to the laboratory for an analysis of nutrients and pollutants. Once the results from the field measurements and laboratory are received, it is possible to create a database and later, after data analysis, to write a report.

This is one way of obtaining an overall picture of the situation, although water quality changes over time, making repeated measurements necessary in order to adequately characterise variations in quality.

The operation of a water quality monitoring station provides an almost continuous record of water quality that can be processed and published or distributed directly by telemetry or other information system. The water quality record provides a nearly complete record of changes in water quality, as well as a basis for computing constituent loads at a station. Data from the sensors can also be used as surrogates for the measurement of other constituents by using regression analyses to provide estimates of instantaneous chemical loads.

Emerging sensor technology is broadening the variety of measurable chemical constituents and is reducing the limits of detection. As it is now possible to make near real-time water quality monitoring data available on business systems, continual progress is being made to improve applications and refine quality control procedures. Table 4 shows the advantages and disadvantages of using sensor technology.

It is important to monitor water quality so that water resources can be managed fairly, contaminants and their effects can be detected and controlled in time, and environmental protection policies and programmes can be assessed. In temporary rivers, it is necessary to ensure the availability of water in order to design the stations and locations for equipment, or the measurement sites.

A strict requirement in this sampling protocol is that samples should be taken from a lotic zone with actively moving water. The river reach to be sampled should be 20 times as long as its width, and should measure a minimum of 20 m and a maximum of 200 m (approximately). In temporary rivers, the sample should be taken in an area where the flow is independent of the substrate. The selected stretch should be at least 50 m upstream of any bridge or any kind of river crossing.

In the respective zone, three (if the river stretch is shorter than 100 m) or four (if it is longer than 100 m) areas should be selected. Each area should measure 2 m², and between them they should include all the substrates and velocities present in the lotic zone.

Samples should be taken in the central areas or at the edges, at depths greater than 0.3 m. To ensure the integrity of the sample, it is important to be aware of possible sources of contamination. Contamination introduced during each phase of sample collection (and processing) is accumulative, and is usually substantially greater than contamination introduced elsewhere in the sample handling and analysis process.

Multiple measurements are needed to allow the calculation of a mean and a confidence interval for the characteristic of interest, or to allow statistical testing for significant differences between locations or non-compliance with statutory provisions.

The steps in the sampling process are outlined in Figure 5. To start the process, it is important to select an appropriate bottle, and to label it, if possible before you collect the sample, using a waterproof pen. The ink should be allowed to dry completely before immersing the container.

A strip of waterproof tape can be fastened around the container to ensure the label does not become detached (making sure that one end of the tape adheres to the other), before the container is placed in a plastic bag.

Where practicable, the sample should be collected directly in the sample container, which should be held either in a gloved hand or by means of a sampling rod. If this is not practicable, the sample can be collected in a sampling beaker and promptly transferred to the sample container, taking care to avoid contamination. If sampling from an open channel, the sample should be taken from the centre of the channel, if possible, where velocity is highest. The mouth of the sampling container should be held well above the base of the channel, to avoid disturbing and picking up any settled solids.

If the water depth permits, the mouth of the sample container should be held approximately 10 cm below the water surface. The surface layer of water often comprises a lipid-rich micro-

### TABLE 4 Advantages and disadvantages of sensor technology

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote locations can be accessed</td>
<td>The water flow cannot be treated to reduce fouling (anti fouling is an option)</td>
</tr>
<tr>
<td>Smaller shelters can be used</td>
<td>In shallow bank installations, the proper location of sensors in the cross section is difficult</td>
</tr>
<tr>
<td>Pumping maintenance is not required</td>
<td>Servicing sensors during flooding can be difficult</td>
</tr>
<tr>
<td>Freeze protection is provided to the sensors</td>
<td>Sensors are susceptible to vandalism, debris and high flow</td>
</tr>
<tr>
<td>Electrical hazards are reduced</td>
<td>Shifting channels may cause movement of the equipment</td>
</tr>
</tbody>
</table>

Fieldwork and sampling
layer that may contain organic contaminants many times more concentrated than the water just below the surface.

As far as possible, the sampler’s hand should be kept out of the flow, to minimise the risk of contaminating the sample or of causing infection or injury. If the sample is to be analysed for substances present in “low” concentrations (e.g. nutrients), any contact between the sample and the sampler’s skin should be avoided. If sampling from a boat in shallow water, be aware that sediment will be stirred up by the boat’s movement. Where this happens, samples should not be collected immediately the boat reaches the site, but only when the sediment has settled. If sampling in deeper waters, samples should not be taken in or near the wake, but from ahead of the boat, using a container on a pole or an intermediate container.

The sampler should avoid:
- scraping the walls of drains, tanks, sewers etc., as this could dislodge adhering matter into the sample, thus making it unrepresentative; and
- disturbing sediment, if sampling in shallow waters, as this could also make the sample unrepresentative of the water column.

The sampler must not:
- smoke during the sampling;
- rinse sample containers with the water or waste being sampled; or
- risk the loss of the preservatives by overfilling sample bottles.

## Biological elements

Due to the importance of defining and collecting biological samples, in the following the main characteristics of biological elements in rivers (macroinvertebrates) and lakes (phytoplankton) are described.

### MACROINVERTEBRATES

The following general guidance can contribute to successful sampling:

- A representative reach for sampling should be selected, based on a walk along the river.
- Account should be taken of vegetation cover; bridges/weirs should be avoided; and the sample point should be accessible.
- The geographical coordinates of the site should be fixed.
- Habitat proportions should be noted, in order to estimate the area covered by each habitat.
- It can be useful to sketch a map of the sampling reach.
- The multihabitat approach involves the sampling of a combination of major stream habitat types colonised by macroinvertebrates.
- A total of 10 replicas (sampling frames) should be used over the length of the reach, with a minimum of one replica in each habitat.
- The sample should be a composite sample, taken from individual sampling spots.
- After every kick sample, the collected material should be washed two to three times in clean running stream water through a net.
- A representative of each taxon should be placed in a properly labelled sample container.
- As much information as possible should be gathered from the field.
- After sampling is completed at a given site, all equipment should be rinsed thoroughly.
- In order to ensure quality standards, sampling should be replicated at 10 percent of the sites.

### Procedure

Pre-sampling site evaluations outline the general sampling locations for each lotic system being assessed. Final decisions on sub-sample locations are made on site, depending on suitability and safety. The riffles chosen should be representative and preferably not dominated by bedrock or boulders. Sampling efforts should initially focus on evaluating the microhabitats of the area and estimating their proportions in order to obtain the most representative sample. Species diversity is generally highest in fast-flowing sections of wadeable riffles.

The sampling section must be representative of the natural variability of physical and structural elements of the river. The following aspects should be taken into account:

- Sub-sampling sites should be selected bearing personal safety in mind. The sub-sampling sites should only be accessed from stable areas of river bank or adjacent sub-sampling sites, using the net handle for stability where the substrate and/or water velocity cause unsteadiness. Samplers should always take precautions and avoid risks.
- The sampling section should be typical of nearby river reaches (both upstream and downstream) in terms of water velocity and depth, and the sub-sampling sites should adequately reflect the pattern of (micro-) habitats that exist in the section.
- The vegetation cover (density, shadow) should be representative of the river stretch. Thus, for example, samples should not be taken from a shaded area if this is not a predominant habitat type in the river stretch.
- Areas around bridges, fords or weirs should be avoided unless they are characteristic of the sampling stretch. Where possible, water should be sampled upstream of the access point (i.e. upstream of bridges etc.).
In addition to the macroinvertebrate samples, physical measurements, site descriptions — including local land use (in a 1 to 2 km radius of the site) and immediate land use (between 100 and 200 m around the monitoring site) — and chemical samples should be collected at each sample location. All taxa must be recorded, regardless of their abundance, and even if only a single specimen is identified in a sample.

If data are to be stored on a computer (in spreadsheets or databases), it should be the responsibility of the analyst to make sure this is done. This task should not be assigned to somebody who has no experience in processing samples or biological data, because of the increased risk of typographical errors not being identified. A different biologist should re-analyse 10 percent of the samples previously analysed by the original analyst, after which the sample (and associated debris) should be replaced in the sample container and marked with the paper identification label. Ideally, both the primary and secondary analyses will produce the same results. If they do not, there are several possible causes of error:

- incorrect identification (misidentified taxa);
- failure to identify rare taxa; or
- differing abundance values produced by different analysts. (Only complete invertebrates should be recorded, but as samples get older they may break into two or many more parts, each of which may be potentially identified.)

The intention here is not to punish poor performers, but rather to use the results of such comparisons to identify where additional training and/or experience is required. While 10 percent is suggested as the appropriate proportion of samples to be re-analysed, this figure should be regarded as a minimum. Ideally, an experienced analyst should re-analyse samples processed by less experienced biologists, although initially all the samples analysed by an inexperienced biologist may need to be re-analysed. Where possible, the re-analysis of samples should be undertaken by personnel from a different laboratory, but this will clearly depend on the number of laboratories involved in monitoring macroinvertebrate communities.

The following (micro-)habitats may be present:

- Stones, boulders, bedrock and other hard substrates are prevalent in riffles and runs, which are a common feature throughout most mountain and piedmont streams. In many high-gradient streams, this habitat type will be dominant. However, riffles are not a common feature of most coastal or other low-gradient streams. In shallow areas with coarse substrates, samples should be taken by holding the bottom of the dip net against the substrate and dislodging organisms by kicking/disturbing the substrate upstream of the net.
- Snags and other woody debris that has been submerged for a relatively long period of time provides an excellent habitat for colonisation. Samples from submerged woody debris should be taken by jabbing at medium-sized snag material, such as sticks and branches. A snag habitat may be kicked first to help dislodge organisms, but only after placing the net downstream from the snag. Accumulated woody materials in pool areas are considered a snag habitat. Large logs should be avoided because they are generally difficult to sample properly.
- Samples from vegetated banks — lower banks that are submerged and have associated roots and emergent plants — should be taken in a similar way as from snags. Samples should be taken from banks with protruding roots and plants by jabbing into the habitat. A bank habitat can be kicked first to dislodge organisms, but only after placing the net downstream.
- Submerged macrophytes are seasonal in their occurrence and may not be a common feature of many streams, particularly those that are at high gradients. Samples from aquatic plants that are rooted to the bottom of the stream in deep water should be taken by drawing the net through the vegetation from the bottom to the surface of the water — a maximum of half a metre per jab. In shallow water, samples should be taken by bumping or jabbing the net along the bottom in the rooted area, avoiding sediments where possible.
- Sand and other fine sediment is usually the least productive macroinvertebrate habitat in streams, although it may be the most prevalent habitat in some streams. Samples from non-vegetated banks or banks with soft soil should be taken by bumping the net along the surface of the substrate, rather than dragging the net through soft substrates. This reduces the amount of debris in the sample.

When samples need to be taken from temporary rivers, the procedure is slightly different. Samples should be taken from each of the three or four areas selected. As the sampling is qualitative, a representative sample should be obtained. The procedure is as follows:

- Remove larger stones from the net.
- If the stones are less than 10 cm in diameter, kick an area equivalent to 1 m and collect all the material disturbed, holding the net against the flow of the river.
- Repeat the above steps in all the selected areas.
- If the samples are to be identified subsequently in the laboratory, they should be preserved in 70 percent ethanol or 4 percent formaldehyde.
- The net should have a mesh of 250µ (and the opening should have a diameter of at least 30 cm).
- The net should be carefully cleaned between two consecutive sampling stations in order to prevent the presence of organisms from the previous sampling.

**PHYTOPLANKTON**

**General ideas**

Several discrete samples should be taken, distributed in the profile. In general:

- at surface level;
- at Secchi depth; and
- at 2.5 times Secchi depth.

Additional samples may be added, for example samples related to observed gradients or profiles.

**Procedure**

- Profile temperature, conductivity, turbidity and dissolved oxygen to identify the pattern of stratification; then take samples at Secchi depth to assess the extension of the photic area, water transparency and eutrophication status.
- Take a surface sample manually, then collect other hydrographic bottle samples from different depths.
- It is recommended to perform an alternative profile with a fluorometer and sampling plan, according to the readings obtained.

The composition and abundance of phytoplankton in lakes and reservoirs depends on the following factors:

- physical conditions, such as light, temperature and water turbulence;
- the chemical composition of the water, nutrient mineralisation and trace elements; and
- predation by planktivorous crustaceans and fish, and relationships between species (some species induce toxicity).
Phytoplankton is suitable for the detection and monitoring of physico-chemical pressures related to:
- thermal pollution;
- changes in water mineralisation;
- eutrophication; and
- organic pollution.

Analysis of the species in an association (algal assemblages) is the most appropriate tool for the characterisation of the different types of lakes and reservoirs, and for obtaining quality indicators.

Hydrological measurements

Hydrological measurements are essential for the interpretation of water quality data and for water resources management. The hydrological regime affects water quality, and variations in hydrological conditions have an important impact on water quality. Flood events may lead to different pollutant concentrations in stream waters. In rivers, factors such as discharge (the volume of water passing through a cross-section of the river in a unit of time), flow velocity, turbulence and stage will influence water quality. A proper water quantity estimation is also necessary for correct water quality monitoring.

Selecting the best monitoring technology for a given location is more complex than ever before. The choice of a simple pressure transducer should take into consideration the type (e.g. piezoelectric, capacitive, inductive, potentiometric, vibrating wire, vibrating cylinder, or strain gauge) and the method of deployment (e.g. bubbler, vented or compensated). For each combination of these technologies there are numerous vendors and products available — and each product has a performance specification that can be characterised by an error band, hysteresis, resolution, sensitivity and time constant.

Discharge estimates are essential when calculating pollutant fluxes, such as where rivers cross international boundaries or enter the sea. In lakes, residence time, depth and stratification are the main factors that influence water quality. A deep lake with a long residence time and stratified water column is more likely to have anoxic conditions at the bottom than a small lake with a shorter residence time and an unstratified water column.

It is important that personnel engaged in hydrological or water quality measurements are familiar, in general terms, with the principles and techniques employed by one another.

Rivers

An adequate interpretation of the significance of water quality variables in a sample taken from a river requires knowledge of the discharge of the river at the time and place of sampling. In order to calculate the mass flux of chemicals in the water, a time series of discharge measurement is essential.

The flow rate or discharge of a river is the volume of water flowing through a cross-section in a unit of time, and is usually expressed as m$^3$s$^{-1}$. It is calculated as the product of average velocity and cross-sectional area, but is affected by water depth, the alignment of the channel, and the gradient and roughness of the river bed. Discharge may be estimated by the slope-area method, using these factors in one of the variations of the Chezy equation.

Site selection plays a crucial role in hydrological monitoring, but it is also dependent on the purpose of the hydrological monitoring. The choice of location will vary depending, for example, on whether the intention is to determine the discharge flowing into a reservoir or a dam, or if the main task is to develop a water resources master plan on a medium to large timescale.

There are some important characteristics to take into consideration. With respect to the monitoring network itself, as a major network that is already in operation or due to be operated, it is essential to bear in mind that climate, geographical and topographical considerations will influence the reliability of the monitoring system. A trustworthy network will allow technicians to better understand any discrepancies between official network and seasonal monitoring visits. The monitoring campaign will also be checked according to existing monitoring data.

A minimum network should include at least one principal hydrological station in each climatological and physiographical province in a region, because the runoff characteristics of streams are related to the climatological, topographical and geological characteristics of the basins they drain and can be highly variable.

When implementing monitoring campaigns, the following aspects should be considered:

a) The stream course should be straight over a length of about 10 times the stream width, upstream and downstream from the gauge site if the control site is a river reach (channel control). If the control is a section control, the downstream conditions must be such that the control is not drowned.

b) The total flow should be confined to one channel at all stages, and no flow should bypass the site as subsurface flow.

c) The stream bed should be relatively free of aquatic vegetation.

d) Banks should be permanent, high enough to contain floods, and free of vegetation.

e) The gauge site should be far enough upstream from a confluence with another stream or from tidal impacts to prevent any variable influence.

f) A satisfactory reach for measuring discharge at all stages should be available within reasonable proximity of the gauge site. It is not necessary for low and high flows to be measured at the same stream cross-section.

g) The site should be readily accessible to facilitate the installation and operation of the gauging station.

h) The gauging site should be within reach of a suitable telemetry system.

i) There should be good conditions for discharge measurements at all stages, and adequate cross-sections for area measurements of discharge speed.

j) Instruments should be located taking into account flood levels. Sensors should have sufficient range to measure floods and drought.

Stream flow monitoring is carried out by measuring discharge. However, there are various options available for making such measurements. Monitoring may be done indirectly through water stage measuring, and may also be performed by measuring discharge at gauge stations.

The water stage is the elevation of the water surface of a stream, lake or other waterbody relative to a datum. Water level monitoring may be used to forecast flow, delineate flood hazard areas, design hydraulic structures, and define low-flow regimes. Different monitoring techniques may be applied, depending on the site location and the purpose of the measuring. Stream gauge water stations include non-recording stations, recording stations, portable devices for echo sounding or portable gauges.

Some considerations to bear in mind when defining water stage monitoring are:

- **gauge datum** — this should be checked annually, and the datum should stay fixed during the recording period. When monitoring water level developments, a regional or national datum system should be adopted for all the stage stations (if a monitoring network already exists the datum to be used should be assessed);

- **flash streams** — this stage should be recorded more frequently in order to obtain a sufficiently accurate hydrograph; and
Fieldwork and sampling

Injecting tracers into the stream, or by the construction of a weir, although these methods are elements of the section or channel that act as the control. The stage-discharge curve is also available, a rough estimate of velocity can be made by measuring the time required for a weighted float to travel a fixed distance along the stream (see Figure 6).

The most accurate method is to measure a cross-sectional area of the stream and then, using a current meter, to determine the average velocity in the cross-section. If a current meter is not available, a rough estimate of velocity can be made by measuring the time required for a weighted float to travel a fixed distance along the stream (see Figure 6).

When measuring velocity, the following should be considered:

- the interval between any two verticals should be <1/20 of the river width;
- discharge from any segment should not be more than 10% Q; and
- the monitoring time should be 30 seconds.

In addition, discharge may be measured using ultrasonic or electromagnetic methods, by injecting tracers into the stream, or by the construction of a weir, although these methods are prohibitively expensive and complex to install and operate.

The stage-discharge relationship for most gauging stations is defined by plotting the measured discharges as the abscissa and the corresponding stage as the ordinate.

The shape of the stage-discharge relationship is a function of the geometry of the downstream elements of the section or channel that act as the control. The stage-discharge curve is also known as the rating curve (see Figure 7). It is a characteristic curve for a stream in relation to what discharge is flowing, depending on the measured stage.

In Figure 6, the indication of water level assumes that a certain discharge is conveyed downstream.

In most cases, data from stream gauges are collected as stage data. In order to model the streams and rivers, the data need to be expressed as stream flow using rating tables. However, a variation in riverbed might lead to an incorrect flow definition. Periodical stream monitoring, and especially monitoring after flood events, would make it possible to keep the status of these relationships updated.

Discharge monitoring visits should be scheduled throughout the year, depending on:

- the stability of the stage-discharge relationship;
- seasonal discharge characteristics and variability; and
- the accessibility of the gauge in various seasons.

Depending on these inputs, a minimum of six to 10 field visits are required. As described above, special conditions such as floods (or snowmelt) may make it necessary to carry out a non-programmed monitoring visit.

Lakes and reservoirs

In lakes and reservoirs, hydrological information is needed for the interpretation of data and the management of water quality. These hydrological measurements are required in two different situations:

- when samples are to be taken from tributaries and outflowing streams; and
- when samples are to be taken from the lake or reservoir itself.

Both types of sampling may be aimed at the estimation of the mass flow of some variable in the waterbody and, consequently, hydrological data are essential.

When sampling from tributaries and outflowing streams, hydrological measurements should be obtained in the same manner as described above for rivers. In tributaries, the location of sampling stations and flow measurement stations should be selected so that backwater effects (water backing up the river from the lake) are avoided. If this is not possible, the water level at the mouth of the tributary should be measured and recorded to provide data on the magnitude of the backwater and its variation with time.

When sampling from a lake or reservoir, the water level at the time of sampling must be measured. If the water surface is calm and a water level gauge has been installed, a single reading may be sufficient. If there is no official gauge, the water level should be recorded in relation to a conveniently located, identifiable point on a rock outcrop, large boulder or other landmark that is reasonably permanent. If there is any reason to suspect that this water level marker might move or be moved, reference should be made to a second landmark. The use of landmarks as a water level reference is a temporary measure and a water level gauge should be installed as soon as possible.
Waves and the inclination of the water surface may cause problems in observations of water levels. High waves may make it difficult for the observer to see the gauge, and the continual motion of the water will make it impossible to determine the exact water level. In such conditions, the observer should try to record the highest and lowest positions of the changing water level and calculate the average. Wind conditions should also be noted, together with an estimate of the height of the waves.

In certain conditions, current measurements in lakes or reservoirs provide information that is helpful in the interpretation of the results of analyses of water and sediment samples. Currents may cause water quality to vary appreciably within short distances or time periods. The flow velocities that normally occur in lakes are measured with sensitive recording current meters anchored at given depths. Sometimes, however, a rough estimate of the flow field can be made by observing the motion of surface floats. In reservoirs, the operation of valves or sluices can create localised currents that can affect the water quality in their vicinity.

Groundwater
This resource is extremely important as it is a major component in the water cycle. The monitoring of groundwater flow is dependent on the defined goal, but also on the availability of monitoring and observation wells.

The main stages to consider prior to groundwater monitoring are:

- reconnaissance — with the objective of a preliminary appraisal of the available water resources;
- applied research — to obtain information for planning future urban, industrial and agricultural development; and
- intensive studies of the aquifer(s) — this level of the investigation requires the greatest effort and is necessary for areas of present or potential intensive development.

The performance of the above stages will necessitate the provision of certain information:

- spatial and temporal variations of the piezometric heads;
- the hydraulic constants of the aquifer;
- the geometry of the aquifer;
- the rates of natural replenishment and outflow;
- the rates of abstraction and artificial recharge; and
- water quality definition.

As in the case of surface water monitoring, there are certain measurement site specifications to be considered after background and data analysis:

- Geostatigraphic zoning — if several aquifers are present in the area with differing piezometric heads and/or different chemical composition or differing concentrations, separate observation wells must be installed in each aquifer.
- Coverage of spatial heterogeneity — each aquifer should be subdivided into zones with relatively common major characteristics. At least one observation well should be placed in each zone. The zoning may be both horizontal and vertical.
- Hydrogeologic continuity — spatial density, if this has not been done in the formal methods, area size, hydrogeology, the objectives of the network and financial limitations must be taken into account.
- Coverage of boundary conditions: Wells should be situated taking into account the slope for computing the piezometric head.

The presence of abandoned wells, observation wells, groups of wells etc., linked to the prerequisite for incorporating existing wells in the network, is a reliable identification of the aquifer to which the well belongs.

Unless deep aquifers are present in the catchment area, water table monitoring in aquifers is connected to surface hydrology and therefore also to water quality in groundwater. Adequate groundwater data are essential for water resources assessment and for the integrated development and management of renewable water resources in wadi basins. Groundwater is also a resource suited to arid regions. The recharge of an alluvial aquifer system by river flows can provide an important resource. Hydrological measurements and subsequent analysis may lead to the investigation and increase of surface–groundwater interactions. Such interactions, including baseflow definition and recharge estimation, are extremely important in defining available water resources (water budget).

Sediment measurements
Sediment measurement may have implications in terms of both water quantity and water quality. Although the two are closely connected, there are specific considerations related to each.

Water quantity and sediment
As noted in the previous section, during high-flow events some changes may occur in cross-sectional areas. In other words, the presence of high flows leads to hydrodynamic changes that can affect the operative cross-sectional area of rivers, and that therefore imply changes or discrepancies in water-level–discharge relations. From an operational point of view, it is extremely important to define such implications and take them into account.

The monitoring of sediments can be an important measure, depending on the streams to be analysed. If no measurements are available, rating curves from different time periods may give some indications of the possible presence of sediments in a stream. The different types of sediments are described below (see also Figure 8).

Suspended sediments are easier to determine visually during monitoring campaigns. Several types of samplers for suspended sediments are in use, such as instantaneous, bottle, pumping or integrating.

In situ monitoring samples of suspended sediments in streams are taken at the discharge-measuring cross-sections, but not necessarily at the velocity-measuring verticals.

Bed sediments are difficult to sample because of their natural movement, and because they exist in the form of ripples, dunes and bars.

Bed material discharge is determined from the amount of sediment trapped per unit of time in a sampler located at one or more points on the stream bed — that is, three to 10 measurement points in a cross-section (related to Xns width and (\textit{Sediment})).

With the exception of flood periods, bed material transport takes place in only a part of the stream width.

It is also important to estimate the presence of sediments in reservoirs, since besides the implications for water quality, due to the possibility of pollutants being trapped in the sediment material, the presence of sediment in reservoirs tends to reduce the storage capacity of the structure. Such a reduction may lower operational standards, water distribution budget and quality, and could also lead, at a given time, to the collapse of the reservoir system. In extreme cases, it might even mean the failure of the reservoir.

Reservoir monitoring involves information about two main parameters: water level and sedimentation (see Figure 9).
The best method for performing proper reservoir monitoring is to define different monitoring campaigns in the reservoir, bearing in mind different considerations:

- seasonal variations in water level;
- sediment dynamics in the upstream river network; and
- the equipment available.

The best methods currently being used are acoustic Doppler current profilers (ADCPs) or sonar devices set up in a boat (Figure 10).

Surveillance makes it possible to measure the actual level of the reservoir bed under similar conditions throughout the whole survey. The variation in reservoir bed is then highlighted when making comparisons with previous monitoring campaigns, or original bathymetry. If sediment dynamics are a major issue in the river network, it is important to track the reservoir sedimentation rate or reservoir bed periodically (every two to three years) so that operational work can be decided in order to improve capacity and to prevent the malfunctioning of structures.

Sediment samples are collected either for an analysis of the chemical and physical properties of the sediment, or to assess the benthic biotic community structure (biomass and/or taxonomy). A number of basic requirements must be met in order to obtain representative sediment samples:

- the sampling device must penetrate the sediment to a sufficient depth to measure the variables of concern accurately;
- the sampling device must enclose the same quantity of sediment each time;
- the sampling device must close completely each time; and
- care should be taken not to disturb the sediments prior to the deployment of the sampling device.
Fieldwork and sampling

Sediments in reservoirs
Regardless of the equipment chosen for sample collection, it is necessary to know the water depth at each station before starting. If water depth information is unavailable, it is recommended that water depth first be measured. Measurement equipment can range from a weighted rope to an electronic depth sounder probe. The following steps should be followed to collect samples from a boat:

(a) Set the grab sampling device with the jaws cocked open. Great care should be taken when handling the device while it is set, as accidental closure can cause serious injuries.

(b) Ensure that the rope is securely fastened to the sampler and that the other end is tied to the boat.

(c) Lower the sampler until it is resting on the sediment. (The sampler’s own weight is sufficient for it to penetrate soft sediment.) At this point, the slackening of the line activates the mechanism to close the jaws of the Ponar and Petersen grabs.

(d) In the case of the Ekman grab, a message should be sent to “trip” the release mechanism.

(e) Retrieve the sampler slowly in order to minimise the effect of turbulence (which might result in the loss/disturbance of surface sediments).

(f) Place a container (e.g. a shallow pan) beneath the sampler just as it breaks the surface of the water.

Sediments in rivers
Sediment sampling in deep sections of rivers and streams rarely involves the use of core samplers, as these devices require that flow be minimal (very few rivers worldwide have sufficiently low flow). Alternatively, core samples can be collected in shallow flowing waters by physically pushing the corer into the sediment by hand.

It is useful to have some understanding of the currents at the sampling site. Strong near-bottom currents can lead to poor equipment deployment, deflect a grab sampler, or require the use of a long cable/wire. Care should be taken to ensure that the weight of the sampler is adequate for working in the particular current conditions and that the sampler collects sediment at or very near the desired sampling site. The following steps should be followed when taking samples from a bridge:

(a) Set the grab sampling device with the jaws cocked open. Great care should be taken when handling the device while it is set, as accidental closure could cause serious injuries.

(b) Ensure that the rope is securely fastened to the sampler and that the other end of the rope is tied to the bridge.

(c) Lower the sampler over the upstream side of the bridge until it is resting on the sediment. (The sampler’s own weight is sufficient for it to penetrate soft sediment.) At this point, the slackening of the line activates the mechanism that releases the jaws of the Ponar and Petersen grabs.

(d) In the case of the Ekman grab, a message should be sent to “trip” the release mechanism.

(e) Retrieve the sampler slowly to minimise the effect of turbulence, which might result in the loss of surface sediments.

(f) Place a container (e.g. a shallow pan) beneath the sampler as soon as it is on the bridge.

Recording field observations
Observations made during measurements can be extremely important when assessing atypical events or long-term trends, especially when investigating pollution incidents. Such observations might include:

- atypical water colour or clarity (such as greenish, muddy, pale brown or cloudy);
- odours;
- wind speed and direction;
- surface scum;
- heavy algal or plant growths;
- dead or dying vegetation in waterways or on banks;
- dead or dying fish;
- flotsam;
- dumped material;
- nearby earthworks or other construction activity;
- nearby agricultural activities; or
- nearby industrial establishments or wastewater treatment works.

As visible conditions can be difficult to describe accurately in words, it is strongly advised to take photographs, which will increase the quality of information from field observations. Photographs are also useful when investigating pollution incidents.
Parameters to be monitored

Groundwater

Groundwater parameters, monitoring frequency, sampling methods and procedures will be the same for all watersheds.

The following quality parameters reflect in general the requirements of the groundwater quality evaluation:

- Descriptive parameters — temperature, pH, dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids, to be measured in the field near the well or spring.
- Major ions — calcium, magnesium, sodium, potassium, hydrogen carbonate (HCO₃), chloride, sulphate (SO₄), ammonium sulphate (NH₄), nitrate (NO₃) and nitrogen dioxide (NO₂).
- Permanganate index (or TOC) and ionic balance.
- Trace elements, as required by the Groundwater Directive — arsenic, cadmium, lead, mercury.
- Organic substances — poly cyclic aromatic hydrocarbons, phenols, trichloroethylene, tetra-chloroethylene (the more precise choice depends on the local pollution sources).
- Pesticides — the choice depends in part on local usage, the land-use framework and existing observed occurrences in groundwater.

Surface water

Parameters that can be used to characterise general quality include pH, alkalinity, total dissolved solids (TDS), turbidity, dissolved oxygen, oxidation/reduction potential (ORP), fluoride (F⁻), hydrogen sulphide (H₂S), total hardness and non-carbonate hardness, specific conductance, chloride (Cl⁻), nitrate (NO₃⁻), sulphate (SO₄²⁻), phosphate (PO₄³⁻), silicate (SiO₃²⁻), sodium (Na⁺), potassium (K⁺), calcium (Ca²⁺), magnesium (Mg²⁺), ammonium (NH₄⁺), total iron (Fe), and manganese (Mn), any other kind of nutrients, organic pollutants, biochemical oxygen demand (BOD) and chemical oxygen demand (COD).

Biological samples and hydromorphological data

The results can provide an overall picture of water geochemistry that is useful for site characterisation. For example, an understanding of geochemistry can help in determining and evaluating changes in water chemistry caused by the release and biodegradation of organic contaminants. Table 5 provides a list of the parameters for controlling water quality in reservoirs and lakes.

Field testing methods and sample collection

Analyses of many important physical, chemical and microbiological variables can be carried out in the field using apparatus made specifically for field use. A significant advantage of field analysis is that tests are carried out on fresh samples whose characteristics have not been contaminated or otherwise changed as a result of storage in a container. This is of special importance for samples that are to undergo microbiological analysis but cannot be transported to a laboratory within the time limits. Some variables must be measured in the field, either in situ or very soon after the sample has been collected. Field analysis is necessary for temperature, transparency and pH. Dissolved oxygen may be determined in the field, or the sample may be treated (fixed) in the field and the remainder of the analysis completed in a laboratory. If samples are to be chemically preserved before being transported to the laboratory, conductivity (if required) must be measured before preservative chemicals are added. Another advantage of field analysis is that samples are highly unlikely to lose the labels that identify the time and place of sampling. Loss of such identification would be disastrous if, for example, many samples have been collected to determine the water quality profile of a river.

Physico-chemical parameters

To obtain accurate results for some quality characteristics, on-site measurement is necessary. The typical field equipment used for this comprises:

- thermometer;
- pH meter;
- dissolved oxygen (DO) meter;
- conductivity meter;
- turbidity meter; and
- Secchi disc.

Some modern field instruments (multi-parameter instruments) can measure more than one quality characteristic — for example both temperature and dissolved oxygen. Note that not all field instruments give results of similar accuracy. It is important to check that the instrument used meets requirements and is calibrated (indicated by documentation of the current

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Parameters to be monitored

It is strongly recommended that the instruments be stored, calibrated, maintained and used according to the manufacturer’s instructions. As a general principle, the calibration should be checked and recorded before and during field use, and at the conclusion of the field check.

Safety during fieldwork

All personnel involved in taking samples of surface water or groundwater are responsible for their own safety by preventing exposure to chemical spills or by avoiding the inhaling of fumes from chemicals. When sampling groundwater aquifers where there is known contamination, or any other location close to wastewater, spills etc., the proper sampling and safety equipment should be taken to the field. All personnel should be trained in the proper use of such equipment.

For their own safety, fieldworkers are recommended to:
- have an adequate map (e.g. with a scale of between 1:10,000 and 1:50,000);
- work in pairs to minimise risks, particularly in remote areas or at unfamiliar sites;
- always use or carry personal floating devices or life vests;
- in sunny conditions, wear polaroid sunglasses that greatly reduce the amount of light reflected off the surface of the water, making it easier to see the river bed and the associated benthic invertebrates;
- carry a mobile phone at all times, sealed in a watertight bag to ensure operability in sunny conditions, and always use or carry personal floating devices or life vests;
- have first-aid supplies at hand;
- avoid attempting to take samples at any site where the water is too deep for comfort (knee deep is typically a suitable guide, although this will also depend on water velocity);
- tie a length of strong rope around the waist and tie the other end to a bankside tree, or ask a colleague on the bank to hold it, to contribute to safety if the river is fast flowing;
- make sure that all sampling personnel are appropriately vaccinated against possible health hazards; and
- always have a second set of clothes and a towel.

Sample preservation

In order to preserve the quality characteristics of the samples and maintain the best conditions for the laboratory analysis, there is a choice of preservation methods in the field for each parameter or group of parameters.

The preservative should be prepared and delivered by the qualified laboratory. Sometimes the preservative can be introduced into the sample bottle from the laboratory. In other situations, the preservative can be added to the bottle in the field. The laboratory should be responsible for preparing the instructions to ensure that the preservation process is carried out correctly.

For microbiological samples, although recommendations vary, the time between sample collection and analysis should, in general, not exceed six hours, while 24 hours is considered the absolute maximum. It is assumed that the samples will be placed immediately in a lightproof, insulated box containing melting ice or ice packs with water to ensure rapid cooling. If ice is not available, the transportation time must not exceed two hours. It is imperative that samples be kept in the dark and that cooling is rapid. If these conditions are not met, the samples should be discarded.

Labelling

Adequate sample descriptions and labelling are extremely important in sampling. Labels should be completed at the sampling site and details recorded in the sampler’s notebook. Samples should be labelled using a waterproof pen to help prevent samples from being mixed up. To guard against possible confusion between samples, each sample should also be given a unique number. This number can be made up of parts containing codes for different pieces of information, if required. However, the label must include at least the following information:
- sample location;
- sample number;
- sampler ID; and
- date.

Quality assurance

If possible, a control sample should be collected from a location not affected by the possible contaminants of concern, and submitted with the other samples. This control sample should be collected as close to the sampled area as possible and from the same water-bearing formation. Equipment blanks should be collected if equipment is field cleaned and re-used on site, or if necessary to document that low-level contaminants were not introduced by pumps, bailers, bottles, probes or other sampling equipment.

Analytical quality assurance

The reliability of data for a water quality monitoring programme depends on strict adherence to a wide range of operating procedures for water sampling and analysis. It is the consistent application and monitoring of these procedures that is referred to as quality assurance. The subject can be confusing, especially if more than one reference work is used as an information source. Different authors may use different terms to describe the same thing, or the same term to describe different things.

In relation to biological sampling, good-quality control starts with good record keeping and the adoption of standardised methodologies by all those concerned with analysing the samples. It also depends on assigning responsibility for individual tasks.
Transportation and storage of samples

To keep samples at suitably low temperatures, they should be transported in cleaned/uncontaminated insulated carrier boxes (coolers). These should be kept cool and preserved at a temperature of below 4°C by adding block or crushed ice, dry ice, freezer blocks or other similar substances, or should be refrigerated by a power source.

Samples requiring refrigeration are generally packed in crushed ice. Crushed ice is used in preference to block ice as it can be packed far more closely in contact with the samples.

After collection, the samples must be transported to the appropriate laboratories, ensuring that the integrity of the samples is maintained. This can be ensured by:

- delivering them personally or sending them by commercial carrier;
- packing sample containers in sample carrier boxes to minimise the risk of breakage, leakage or spillage during transportation;
- handling and storing sample carrier boxes so as to protect the samples;
- applying appropriate security measures; and
- providing documentation to accompany the samples.

Suggested preservative treatments and maximum permissible storage times are shown in Table 6.

In the case of all samples, an identifier must be included on every page of the documentation related to samples shipped or delivered in person to the laboratory. Custody logs should reflect only those sampling sites from which samples are contained in the cooler.

Custody logs, field sheets (electronic and handwritten), equipment blanks, duplicate sheets and reference sample sheets will be checked for accuracy by the sampling personnel. Any corrections made to documentation should not obliterate the original entry.

In the case of biological samples, samples should arrive unaltered and suitable for laboratory analysis.

Reception of samples by the laboratory

When a sample carrier box or freezer from the carrier are received, a chain of custody sheet should be completed and a receipt issued.

On delivery, checks should be carried out to ensure that:

- the locks and chain are intact; and
- there are no signs that the carrier box or freezer has been tampered with;

Once the sample carrier box or freezer has been opened and the sample container/s removed, checks should be carried out to ensure that:

- all samples referred to in the completed analysis request are present;
- the security seals are intact; and
- there is no sign that the samples have been tampered with.

If there is any reason to suspect tampering, the sampler should be contacted immediately to determine whether the samples should be analysed or not. The results of the checks should be recorded, along with any actions taken because of them.
### TABLE 6 Suggested preservative treatments and maximum permissible storage times

<table>
<thead>
<tr>
<th>Variable</th>
<th>Recommended container (tare containers can be used to replace polyethylene or glass)</th>
<th>Preservative</th>
<th>Maximum permissible storage time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalinity</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>24 hours</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Polyethylene</td>
<td>2 ml conc. HNO₃ ¹ sample</td>
<td>6 months</td>
</tr>
<tr>
<td>Arsenic</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>6 months</td>
</tr>
<tr>
<td>BOD</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>4 hours</td>
</tr>
<tr>
<td>Boron</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>6 months</td>
</tr>
<tr>
<td>Cadmium</td>
<td>Polyethylene</td>
<td>2 ml conc. HNO₃ ¹ sample</td>
<td>6 months</td>
</tr>
<tr>
<td>Calcium</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>7 days</td>
</tr>
<tr>
<td>Carbonic acids</td>
<td>Plastic Petri dish</td>
<td>Filter using GF/C filter; cool 4°C</td>
<td>6 months</td>
</tr>
<tr>
<td>Chloride</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>7 days</td>
</tr>
<tr>
<td>Chlorinated hydrocarbons</td>
<td>Glass</td>
<td>Cool 4°C</td>
<td>Extract immediately</td>
</tr>
<tr>
<td>Chlorophyll</td>
<td>Plastic Petri dish</td>
<td>Filter on GF/C filter; freeze -20°C</td>
<td>7 days</td>
</tr>
<tr>
<td>Chromium</td>
<td>Polyethylene</td>
<td>2 ml conc. HNO₃ ¹ sample</td>
<td>6 months</td>
</tr>
<tr>
<td>CO₂</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>24 hours</td>
</tr>
<tr>
<td>Copper</td>
<td>Polyethylene</td>
<td>2 ml conc. HNO₃ ¹ sample</td>
<td>6 months</td>
</tr>
<tr>
<td>Dissolved oxygen (Winkler)</td>
<td>Glass</td>
<td>Fix on site</td>
<td>6 hours</td>
</tr>
<tr>
<td>Fluoride</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>7 days</td>
</tr>
<tr>
<td>Iron</td>
<td>Polyethylene</td>
<td>2 ml conc. HNO₃ ¹ sample</td>
<td>6 months</td>
</tr>
<tr>
<td>Lead</td>
<td>Polyethylene</td>
<td>2 ml conc. HNO₃ ¹ sample</td>
<td>6 months</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>7 days</td>
</tr>
<tr>
<td>Manganese</td>
<td>Polyethylene</td>
<td>2 ml conc. HNO₃ ¹ sample</td>
<td>6 months</td>
</tr>
<tr>
<td>Mercury</td>
<td>Glass or teflon</td>
<td>1 ml conc. H₂SO₄ + 1 ml Sn 2Cl₂</td>
<td>1 month</td>
</tr>
<tr>
<td>Nickel</td>
<td>Polyethylene</td>
<td>2 ml conc. HNO₃ ¹ sample</td>
<td>6 months</td>
</tr>
</tbody>
</table>

*Source: Adapted from UNEP/WHO 1996*

### TABLE 6 (continued)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Recommended container (tare containers can be used to replace polyethylene or glass)</th>
<th>Preservative</th>
<th>Maximum permissible storage time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td></td>
<td>Cool 4°C, 2 ml 40% H₂SO₄ ¹¹</td>
<td>24 hours</td>
</tr>
<tr>
<td>Ammonia</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>24 hours</td>
</tr>
<tr>
<td>Kjeldahl</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>24 hours</td>
</tr>
<tr>
<td>Nitrate + Nitrite</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>24 hours</td>
</tr>
<tr>
<td>Organic nitrogen</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>24 hours</td>
</tr>
<tr>
<td>Organic particulates</td>
<td>Plastic Petri dish</td>
<td>Filter using GF/C filter; cool 4°C</td>
<td>6 months</td>
</tr>
<tr>
<td>Organophosphorus pesticides</td>
<td>Glass</td>
<td>Cool 4°C, 10% HCl to pH 4.4</td>
<td>No holding, extraction on site</td>
</tr>
<tr>
<td>Pentachlorophenol</td>
<td>Glass</td>
<td>H₂SO₄ to pH &lt; 4, 0.3 g CuSO₄/F sample; cool 4°C</td>
<td>24 hours</td>
</tr>
<tr>
<td>pH</td>
<td>Polyethylene</td>
<td>None</td>
<td>6 hours</td>
</tr>
<tr>
<td>Phenolics</td>
<td>Glass</td>
<td>H₂PO₄ to pH &lt; 14, 0.5 g CuSO₄/F sample; cool 4°C</td>
<td>24 hours</td>
</tr>
<tr>
<td>Phenoxy acid herbicides</td>
<td>Glass</td>
<td>Cool 4°C</td>
<td>Extract immediately</td>
</tr>
</tbody>
</table>

*Phosphorus*

<table>
<thead>
<tr>
<th>Variable</th>
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<th>Preservative</th>
<th>Maximum permissible storage time</th>
</tr>
</thead>
<tbody>
<tr>
<td>- dissolved</td>
<td>Glass</td>
<td>Filter on site using 0.45 μm filter</td>
<td>24 hours</td>
</tr>
<tr>
<td>- inorganic</td>
<td>Glass</td>
<td>Cool 4°C</td>
<td>24 hours</td>
</tr>
<tr>
<td>- total</td>
<td>Glass</td>
<td>Cool 4°C</td>
<td>7 days</td>
</tr>
<tr>
<td>Potassium</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>7 days</td>
</tr>
<tr>
<td>Rosidue</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>7 days</td>
</tr>
<tr>
<td>Selenium</td>
<td>Polyethylene</td>
<td>1.5 ml conc. HNO₃ ¹ sample</td>
<td>6 months</td>
</tr>
<tr>
<td>Silica</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>7 days</td>
</tr>
<tr>
<td>Sodium</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>7 days</td>
</tr>
<tr>
<td>Electrical conductivity</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>24 hours</td>
</tr>
<tr>
<td>Sulphate</td>
<td>Polyethylene</td>
<td>Cool 4°C</td>
<td>7 days</td>
</tr>
<tr>
<td>Zinc</td>
<td>Polyethylene</td>
<td>2 ml conc. HNO₃ ¹ sample</td>
<td>6 months</td>
</tr>
</tbody>
</table>

*Source: Adapted from UNEP/WHO 1996*
Data restitution

Data are collected by field technicians and recorded on handwritten field sheets during work. At the end of each work week, each field data file is entered into an electronic spreadsheet on an office personal computer, in a database-compatible format.

The success of any monitoring programme ultimately depends on providing feedback on water status to the general public, policy makers, and particularly stakeholders involved in implementing programmes of measures. Reporting includes a strong element of online reporting, through an environmental data exchange network as described above, such that results must be disseminated as quickly and as widely as possible.

The water monitoring programme will be integrated with most of the existing monitoring networks and databases in each country in national programmes.

References

**General survey sampling**


**Surface water**

U.S. Environmental Protection Agency manuals on water monitoring:

www.epa.gov/owow/monitoring/volunteer/stream

www.epa.gov/owow/estuaries/monitor

www.epa.gov/owow/monitoring/lakevmonitor.html

www.epa.gov/owow/wetlands/monitor/volmonitor.html

**Biological elements**


Introduction

In the context of water resources management, water balance is calculated in order to obtain a detailed overview of water availability. In arid and semi-arid areas, the calculation is complex but has even greater importance.

The water budget is the accounting of all the water that flows into and out of a project area. This area may be a wetland, lake or any other point of interest. Human development may alter the natural supply of water and may have a severe impact on a given area, especially if there are nearby ponds or wetlands. A water budget is required in order to determine the magnitude of such impacts and evaluate possible mitigation actions.

Purpose of the present annex

This annex provides general guidance on a common technique and methodology to calculate water balance at a given temporal and spatial scale. It is intended as a support document for agencies and technicians involved in water monitoring in the MENA region, and special attention is given to the regional characteristics of individual watersheds in Jordan and Tunisia.

As several different organisations and institutions are responsible for water monitoring in each region, it is important that they follow the same procedures for data exchange and carry out trend analyses using comparable data and a consistent approach.

Target audience

The present guidance is intended to help:

- water monitoring technicians to undertake monitoring programmes themselves;
- water project leaders and managing experts to undertake monitoring and data processing;
- policy makers to integrate relevant calculations in the policy-making process; and
- policy makers to report on results to the water authority, or to exchange results with other organisations or countries.

Water balance in MENA countries

Water balance analysis is more complex in arid or semi-arid areas, mainly because actual transpiration is far less easy to predict. Because surplus soil moisture seldom gives rise to widespread runoff, the runoff process is more likely to depend on surface flow from local intense storms when rainfall exceeds local infiltration. This water balance analysis approach is based mainly on Horton’s concept of runoff, which might be different in more temperate conditions where there is likely to be greater runoff.

Arid conditions require more complex analysis than humid locations. If the runoff process were to be modelled physically, it would be necessary to monitor rainfall on a very detailed scale, both in terms of the timescale required to estimate rainfall intensity, and in order to take account of the greater spatial variability in shorter time intervals. However, it will be shown that it is possible to use models based on monthly time intervals by making assumptions about the distribution of rainfall and basin conditions.
Water budget

A water budget describes the various components of the hydrological cycle. These components are shown in Figure 1. The water budget typically includes:

- Precipitation (P)
- Evaporation (E)
- Evapotranspiration (ET)
- Surface runoff (SF)
- Groundwater flow (GF)

The water budget is expressed as an equation:

$$\Delta S = P - E - ET \pm SF \pm GF$$

where $\Delta S$ is the difference or changes in water storage.

If the right-hand side of the equation is positive, storage will increase and the water level in the area of interest will rise. A positive change in storage is often termed a surplus, while a decrease in storage is termed a deficit. The change in storage is usually described in millimetres cubed ($\text{mm}^3$) or centimetres cubed ($\text{cm}^3$), according to the International System of Units.

Precipitation (P)

Precipitation is the main water input to the hydrological cycle and is evaluated for all water budget calculations. It is a basic component, and data for a normal year should be used to evaluate the long-term impacts of a project.

It is important to bear in mind that in the wettest year there may be abundant rainfall in the spring and autumn, while the summer may be relatively dry. On the other hand, in what appears to be a normal or drier year, most of the rainfall may be concentrated in the summer months. It may be more useful to examine the rainfall data and look specifically at the May to September rainfall to determine which years to analyse. The existence of a long track record in different locations may make it possible to better define the approach and assessment of different temporal scope definitions.

Precipitation data should be tabulated by month when evaluating the annual water budget. As recommended for all components, the analysis will be facilitated by entering the data into an Excel spreadsheet.
Evaporation (E)
Evaporation, as distinct from evapotranspiration, is the process by which liquid water from an open water surface is converted directly into water vapour. A national network, different types of stations or reservoirs measure evaporation in an evaporation pan measuring 4 feet in diameter and 10 inches deep, and elevated approximately 6 inches above the ground to allow for air circulation around the entire pan. Evaporation data are currently collected at different weather stations. Monthly pan evaporation data may also be available among the data from different institutions, and the processing of such data is a valuable task.

Evaporation measured in a pan is always greater than the evaporation that would occur from a lake or a pond. The measured evaporation must therefore be multiplied by a coefficient (typically around 0.7) to convert the observed values to an estimated value for lakes and ponds.

Evapotranspiration (ET)
Evapotranspiration is similar to evaporation, but refers to the combined effect of evaporation from the land surface and transpiration from growing plants. While evaporation is controlled exclusively by climatic factors, evapotranspiration also depends on the type of soil and plants. Evapotranspiration is typically determined by first computing the potential evapotranspiration (ETP), which is the maximum amount of water loss if the plants have a constant supply of soil moisture.

Evapotranspiration may be computed using the method devised by Thornthwaite and Mather (1957). This method allows for adjustments in order to estimate evapotranspiration.

In some cases, evapotranspiration may need to be evaluated for a specific month. Real-time monitoring and historical evapotranspiration data are highly important for such purposes.

In practice, both evaporation and evapotranspiration are tabulated for each month, or for the crop or growing season, and the higher value is then used in the water budget. In general terms, evaporation is more relevant when the assessment is related to reservoirs or lakes, while evapotranspiration plays a major role in wetland environments.

Surface runoff
Depending on climatic and geographical conditions, surface runoff may be an important component in water budget calculations. Unless the pond or wetland is at the bottom of a slope that normally collects and holds surface runoff, this runoff may be needed to keep the wetland from drying out in the summer, or at least provide sufficient water on a seasonal basis. Down-gradient wetlands can also be deprived of water if the surface runoff is diverted to a stormwater basin or collected by storm sewers and rerouted to another discharge point. While these computations are not particularly difficult, they are laborious. The surface runoff component should only be determined if the other factors produce an inconclusive answer.

Surface runoff is typically computed using the runoff curve number method, which was developed by the United States Soil Conservation Service (US SCS) in 1954. The runoff curve number is based on the area’s hydrologic soil group, land use, treatment and hydrologic condition (Table 1). Each combination is assigned a curve number, which indicates its runoff potential. The curve numbers for various combinations of soils and land use are based on the antecedent moisture condition. The average antecedent moisture condition is termed AMC II. If moisture conditions are dry (AMC I) or moist (AMC III), the curve number must be adjusted.

---

**TABLE 1 Curve numbers**

<table>
<thead>
<tr>
<th>Cover type</th>
<th>Hydrologic condition</th>
<th>AMC I</th>
<th>AMC II</th>
<th>AMC III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbaceous — mixture of grass, weeds and low-growing brush, with brush being the minor element</td>
<td>Poor</td>
<td>80</td>
<td>87</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>71</td>
<td>81</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>62</td>
<td>74</td>
<td>85</td>
</tr>
<tr>
<td>Oak-aspen — mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple and other brush</td>
<td>Poor</td>
<td>66</td>
<td>74</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>48</td>
<td>57</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>30</td>
<td>41</td>
<td>48</td>
</tr>
<tr>
<td>Pinyon-juniper — pinyon, juniper or both; grass understory</td>
<td>Poor</td>
<td>75</td>
<td>85</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>58</td>
<td>73</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>41</td>
<td>61</td>
<td>71</td>
</tr>
<tr>
<td>Sagebrush with grass understory</td>
<td>Poor</td>
<td>67</td>
<td>80</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>51</td>
<td>63</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>35</td>
<td>47</td>
<td>55</td>
</tr>
<tr>
<td>Desert shrubs — major plants include saltbush, geesefoot, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus</td>
<td>Poor</td>
<td>63</td>
<td>77</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>55</td>
<td>72</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>49</td>
<td>68</td>
<td>79</td>
</tr>
</tbody>
</table>

- Poor: <50% ground cover or heavily grazed with no mulch; Fair: 50-75% ground cover and not heavily grazed; Good: >75% ground cover and light or only occasionally grazed.
- Where the actual curve number is less than 30, use CN = 30 for runoff computation.
- The curve numbers shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the curve numbers for woods and pasture.
Groundwater flow (GF)

Groundwater flow can be an important consideration depending on geographical context. The water budget is calculated using groundwater flow, precipitation and evaporation.

In order to determine the groundwater flow component, it is necessary to have an estimate of the hydraulic conductivity (K) of the soil, or its ability to transmit water. The value of K can be estimated from well records and is usually determined by the person doing the calculation. The calculation of the total groundwater flow into the project area also requires the cross-sectional area and the slope (S0) of the groundwater head contours. The saturated thickness of the aquifer (B) can usually be determined from well records. Calculating the width (W) of the aquifer that flows into the project area requires knowledge of the groundwater head contours. A good estimate of this value is the maximum width of the excavated lake, viewed looking "into" the direction of the groundwater flow. The slope of the groundwater head contours should be determined from well records or other recorded water levels by the person doing the calculation.

The total groundwater flow (GF) is calculated using Darcy’s Law:

\[ GF \text{ (m}^3/\text{day)} = K \text{ (ft/day)} \times B \text{ (m)} \times W \text{ (m)} \times S0 \text{ (m/m)} \]

If the change in storage shows a net deficit, the effect on water can be estimated by assuming that this net deficit is equivalent to a pumping well located in the centre of the area. A simple well hydraulics analysis based on this equation is used to compute the drawdown.

Some of these parameters are determined during field monitoring campaigns. Additionally, a well-performing network would make it possible to determine interaction problems and behaviour in surface-subsurface zones.

Purpose of the water budget

The principal reason for introducing the concept of the water budget is the need to verify and assess the availability of water resources on a different temporal scale. This temporal scale is to be evaluated according to the performed analysis. The assessment of water quantity in relation to its temporal and spatial variability plays a major role in any water resources management plan.

The water budget describes how the income, outflow and storage of water vary over the course of an average year (see Figure 2). The local water budget may show periods of water deficit, when the total supply is less than the total demand; and it may show a surplus when there is more water available than can be used or stored. The water budget is a tool that is used to analyse the changes that occur within an area/catchment. This tool is an approximation for a general area and does not always represent specific conditions in all locations within the region. Depending on the time at which the water balance is assessed, and especially on the reliability of the data, a real-time assessment of water resources in terms of status, quantity and availability is performed.

The goal of water budget calculations is to determine how to improve water resources management in an aggressive environment, under extreme climatic conditions, and under water scarcity patterns as occur in arid and semi-arid areas.

The water balance calculation is also used to consider and evaluate monitoring network systems. As the main input data to a water budget calculation, the hydrological network provides the scope for identifying inconsistencies and gaps in terms of water budget components.
Analysis of Alquerias River data

This annex outlines the steps to be taken to analyse annual patterns and compare them with long-term evolution using the flow duration curve generated with data from the Alquerias River.

**Step 1:** Download and copy the time series “Alquerias_St” into an Excel spreadsheet

**Step 2:** Download the chronological record of discharge (daily values)
Step 3: Compute the total number of time step intervals in the period of record

Step 4: Rank discharge by magnitude
- Use the “sort” command to rank the entries by discharge, from largest to smallest.
- Calculate the average value of the variable of interest within each time step (average daily value) for the period of record and note the largest and smallest of these average values.
Step 5: Divide the range of average values into classes (class sizes need not be equal)

20 equal class intervals:

Step 6: Beginning with the upper boundary of the highest class, add up the total number of values that are greater than the lower boundary for each successive class.
Step 7: The cumulative number of occurrences is converted to a percentage of the time
- Divide the values developed in Step 6 by the total number of time steps from Step 2. This gives the frequency with which the lower values of each class have been equalled or exceeded in the period of record.

Step 8: Finally, the diagram is turned so that discharge is given on the vertical axis and exceedence frequency is given on the horizontal axis.
Introduction

In water resources management, discharge calculation is necessary in order to obtain a detailed overview of water flow and temporal flow variation. In arid and semi-arid areas, this exercise is even more important, although complex to perform.

Discharge calculation is related to the velocity of water flowing through a given area. It measures the volume of water flowing along a cross-section of a river or stream. Water flow is a variable that must be known for the purposes of water management for various uses (drinking water rate, ecological flow, flood release etc.).

The purpose of the present annex

The purpose of the present annex is to provide guidance on a general approach and common technique and methodology to calculate discharge at a given cross-section, on both temporal and spatial scales. It is intended as a support document for agencies and technicians involved in water monitoring in the MENA region, giving special attention to the regional characteristics in each watershed in Jordan and Tunisia.

Due to the different organisms and institutions in charge of water monitoring in each region, it makes sense to follow the same procedures for data exchange and trend analysis using comparable data and a consistent approach.

The present annex provides instructions on how to perform a cross-sectional discharge calculation, the use and calculation of rating curves, and the performance of a flow duration curve.

Target audience

The present guidance will help you to do your job, whether you are:

- a water monitoring technician undertaking monitoring programmes yourself;
- a water project leader leading and managing the experts who are undertaking the monitoring and data processing;
- using calculations to take part in the policy-making process; or
- reporting on results to the water authority.

Discharge measurement in MENA countries

Discharge analysis is more complex in arid or semi-arid areas, where surface flow may vary depending on local intense storms, ephemeral rivers and fluctuations in weather (rainfall). It is therefore important to keep a temporal record of river flow, which can be obtained during a monitoring campaign.

Monitoring visits make possible the better analysis of actual flow, cross-sectional status, and the working pattern of the monitoring network. Discharge calculation also makes it possible to determine and revise the river pattern flow itself. Fluctuation in the flow regime may interfere with early warning advice given to the population. The correct functioning of measurement stations may make it possible to establish different stage-discharge relations. Such relations may make it possible to establish rating curves, which will influence the determination of warnings and announcements in terms of reservoir release and operation, civil protection activation protocols, and water resource availability — and therefore water use.

River discharge/flow

Discharge is the volume of water moving down a stream or river per unit of time, commonly expressed in cubic metres per second. In general, river discharge is computed by multiplying the area of water in a channel cross-section by the average velocity of the water in that cross-section (Figure 1).

Discharge at any given time can be measured using several different methods, and the choice of methods depends on the conditions encountered at a particular site.

The performance of discharge measurements described in this document requires the use of a current meter. The stream channel cross-section is divided into numerous vertical subsections (Figure 2). In each subsection, the area is obtained by measuring the width and depth of the subsection, and the water velocity is determined using a current meter. The discharge in each subsection is computed by multiplying the subsection area by the measured velocity. The total discharge is then computed by adding together the discharge from each subsection.

Discharge measurement steps

To better illustrate the performance of discharge calculation, this document provides a general guide to the steps required for calculating accurate surface water discharge measurements, including considerations for selecting the optimum monitoring site, the measurement of cross-section geometry, the measurement of water flow, and the final discharge calculation.

Selection of the monitoring site

In order to calculate the most accurate surface water discharge measurements, several aspects should be taken into consideration. Although these considerations have already been introduced in the guidance document, it is important to highlight that the ideal measurement site should have as many of the following characteristics as possible:

- The stream course should be straight for a length of about 10 times the stream width, upstream and downstream from the gauge site if the control is a river reach (channel control). If the control is a section control, the downstream conditions must be such that the control is not submerged.
- The total flow should be confined to one channel at all stages, and no flow should bypass the site as subsurface flow.
- The stream bed should not be subject to scour and fill and should be relatively free of aquatic vegetation.
- Banks should be permanent, high enough to contain floods, and free of brush.

![Discharge calculation approach](https://via.placeholder.com/150)
The measuring site should be far enough upstream from a confluence with another stream or from tidal effects to avoid any variable influence.

There should be good conditions for discharge measurements at all stages; and adequate cross-sections for velocity area measurements of discharge.

### Cross-sectional geometry

Once a potential site has been selected based on the visual characteristics described above, the next step is to determine the cross-sectional geometry (Figure 3). To calculate this, the width of the cross-section and the depth at a certain vertical point must be measured. In many streams or rivers, especially ephemeral watercourses or wadis, the width can be measured using a measuring tape or a tag line strung at a right angle across the cross-section. However, in the case of a wide river, it may not be so easy to carry out measurements using the above approaches. In such cases, surveying techniques or a global positioning system with differential correction (DGPS) instruments can be used. Once the width has been determined, the river or stream can be divided into equal vertical subsections, where ideally no subsection includes more than 5 to 10 percent of the total discharge of the river or stream.

The depth of the river or stream can then be determined for each of the verticals. Stream depth is usually measured using a wading rod, sounding lines, and weights or depth sensors integrated into instruments such as pressure cells or acoustic echo sounders. Current meters usually feature a type of wading rod device, allowing depth measurement to be incorporated more easily. Once the depth and width of each sub-section is known, the area of the subsections as well as the cross-sectional area can be calculated.

Cross-sectional geometry width measurements make it possible to define the number of profiles to be taken into account. This is a dynamic process and is thus affected by the expertise of the technician as well as the cross-sectional characteristics. The definition of subsections will be also adopted from the point of view of the velocity measurement. It will then be considered that:

- the interval between any two verticals is <1/20 of the river width; and
- the discharge of any segment is not more than 10% of the Total

\[
Q_{Total} = ( \text{Area}1 \times \text{Velocity}1) + ( \text{Area}2 \times \text{Velocity}2) + \ldots + ( \text{Area}n \times \text{Velocity}n)
\]

### Water velocity

Once the channel cross-sectional geometry is known, the next step is to determine the velocity of the flowing water (Figure 4). Current velocity meters usually apply the subsection method. This method requires the calculation of the mean velocity in each of the selected verticals related to each subsection.

Velocity is determined by placing the meter in the stream and counting the number of revolutions in a measured amount of time. Each current meter has a specific rating table (Figure 5). The relation between the number of revolutions can then be determined using its characteristic standard table. Depending on the characteristics of each device, an equation is applied consisting of the calibrated coefficients and a relation with the revolutions measured. It should be highlighted that, as general rule, velocity should be measured for longer than 30 seconds to avoid any mistake in adopting stable vertical velocity measurements.

The mean velocity in a vertical is obtained by taking velocity measurements at many points in a vertical, although the common approach is to take just a few velocity measurements and use a known relationship between those velocities and the mean in the vertical. The goal is then to represent the average velocity in the vertical:

- measured at 0.6 depth when depths are shallow;
- measured at 0.2 and 0.8 depth when depths are large.

These two velocities are averaged to represent average velocity in the vertical; and

- a three-point method by averaging the velocity measured at 0.2 and 0.8 depth and averaging that result with the velocity measured at 0.6 depth.

A common standard is used to measure two points. However, if the velocity at 0.8 depth is greater than the velocity at 0.2 depth, or if the velocity at 0.2 depth is twice the velocity at 0.8 depth, then the velocity profile is considered abnormal and the three-point method should be used (common approach and rule) (Figure 6).

The uses of the 0.6 and the 0.2/0.8 methods assume that the velocity profile is logarithmic.

Velocity measured at a site should decrease closer to the bottom due to friction.
**Discharge calculation**

Final discharge flowing through a river or stream should then be calculated according to the formula:

\[ Q = A \cdot V \]

This formula is adapted to each subsection, so that the total discharge can be characterised by adding together all the subsection discharge calculations (Figure 7).

**Velocity measurement form**

When organising a field visit, site information must always be reported in a spreadsheet or document. This will make it possible to take additional notes and to check whether measurements are correct. The form illustrated in Table 1 is a field visit sheet for use when undertaking this type of survey. Although the type of form may vary, depending on the institution and agency, as a general rule they should all include at least the items in Table 1.

The velocity measurement form is shown in Table 2, while Table 3 shows the type of information to be gathered during the site visit.

---

**TABLE 1 Site visit form**

<table>
<thead>
<tr>
<th>Date:</th>
<th>Stream name:</th>
<th>Latitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspector:</td>
<td>Site ID:</td>
<td>Longitude</td>
</tr>
<tr>
<td>Total control points</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Weather conditions**

- Now:  
  - storm (heavy rain)  
  - rain (steady rain)  
  - showers (intermittent)  
  - % cloud cover  
  - clear/sunny  

- Has there been heavy rain in the last 48 hours?  
  - YES  
  - NO  

| OTHER:  
  | Stream modifications | YES | NO  
  | Diversions | YES | NO  
  | Discharges | YES | NO |

---

**TABLE 2 Velocity measurement form**

<table>
<thead>
<tr>
<th>River</th>
<th>Transect</th>
<th>Device</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transect</td>
<td>Helice</td>
<td>Device</td>
<td></td>
</tr>
</tbody>
</table>

---

**TABLE 3 Site measurement form – Type of information to be gathered during a monitoring visit**

<table>
<thead>
<tr>
<th>Time</th>
<th>Water level (cm)</th>
<th>Distance (cm)</th>
<th>Depth (m)</th>
<th>Revolutions</th>
<th>Measuring time (sec)</th>
<th>a</th>
<th>B</th>
<th>Observations</th>
<th>Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30°</td>
<td>Right bank</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

* This variable might be dependent on the current meter in use. Some current meters have these two coefficients, others do not.
Rating curve

The stage-discharge relationship, or rating curve, usually includes the extremes of discharge encountered in a normal year. The rating curve should be checked periodically, ideally once a year, since minor adjustments may be necessary in order to take account of changes in the cross-section of the stream or instability in the flow characteristics, or to eliminate errors in previous measurements.

Systematic variation as a result of unstable flow may be apparent if the stage-discharge relationship for a single flood event is examined. The discharge during the rising phase of a flood event is usually greater than that during the falling phase of the same flood event. While unstable flow can produce a loop in the stage-discharge graph for an individual storm event, it is not usually apparent in the annual rating curve that is commonly used in hydrological survey programmes. Unstable cross-sections cause stage-discharge variability and can produce sudden and significant shifts in the rating curve as a result of erosion or the deposition of material in the river bed.

The stage-discharge relationship for most gauging stations is defined by plotting the measured discharges as the abscissa and the corresponding stage as the ordinate.

The shape of the stage-discharge relationship is a function of the geometry of the downstream elements of the section or channel that acts as the control (Figure 8).

There are three main types of rating curves:

- Single-value stage-discharge relationship, for stations with a steady geometrical reach and steady hydraulic control.
- Loop rating curve (hysteresis effect) for stations located in an unsteady geometrical reach of the river.
- Loop rating curve for stations located in an unsteady hydraulic flow regime reach of the river.

The points distribution analysis on the graph makes it possible to identify the type of the rating curve (see Figure 9).

![Figure 8: Stage-discharge curve](image1)

![Figure 9: Types of rating curve](image2)
Rating curve graph
To determine the rating curve of a cross-section (normally to calibrate monitoring station locations), the need for two types of data has already been highlighted:

- water level time series; and
- discharge data.

WATER LEVEL TIME SERIES
Time series are obtained from the water level data produced by water level recorders. The staff gauges are normally calibrated in centimetres, although sometimes during the installation of the device, or after some event, the vertical alignment is affected and corrections need to be made.

Water level series are generally computerised and defined by:

- duration — the date and time of the beginning and the end of the observations;
- range — the maximum and minimum observed water levels;
- continuity — the absence of gaps in the observations;
- reliability — observations that are sufficiently dense, with a good time distribution, allowing the accurate reconstruction of water level variations; and
- homogeneity — all observations must relate to a single cross-section and a single set of staff gauges, without any variation in altitude.

A good knowledge of the station often makes it possible to perform a first-sight analysis of the data on a specific rating curve.

DISCHARGE DATA
Each discharge measurement should be checked before being plotted on the graph.

The duration of the measurement, the number of verticals, the methodology used, the location of the measurement cross-section, the values of the cross-section, the mean velocity, and the width of the river are generally good criteria for estimating the quality of a discharge measurement. Following this work, a discharge measurement time series, showing measurement distribution, should be generated.

DRAWING THE RATING CURVE GRAPH
The rating curve graph can be drawn by hand or automatically, respecting the following rules:

Arithmetic coordinates — All the discharge measurements must be plotted, using different graphic symbols to easily identify measurements belonging to the same time series (e.g. year) or any characteristic able to guide the analysis (flood or recession, different gauging cross-sections, same current meter). It is important that the sheet format used for the graph allows a global vision, without any distortion of the point distribution. It is recommended to plot all the gauging, as this will allow the operator to see any trend or specificity in point distribution. The measurements must be plotted on an arithmetic or logarithmic coordinate graph, and must be:

- exact, meaning in accordance with the conclusion of the analysis; and
- accurate, meaning that all the discharge values are read with a minimum of error.

Two rules should be applied:

- Equal point distribution on both sides of the curve — This rule is applied in successive segments, as far as the point density allows, in such a way that all the unevenness of the drawing are taken into account (Figure 10).
- The smallest possible deviation to the curve — The deviations are taken on the discharge axis (the precision of the water level being greater than the precision of the discharge).

The drawing is done in segments, starting with the segments that have the most numerous points. A drawing based on just a few isolated points will not be very accurate.

RATING CURVE EXAMPLE
The following exercise includes the operation of stage–discharge relation curves — that is, the establishment of a rating curve from the gauge station measures, and a comparison between calculated and measured data (Table 4 and Figure 11). This rating curve exercise can be extremely important in streams where flow regimes have a big influence due to the presence of sediment or merely due to the clear difference between dry and wet seasons. Flood events may modify the measuring section, and any prior relation should therefore be re-calculated and checked after such an event.

Once a duration curve is generated (see Figure 11), a further discharge analysis can be carried out. It is a useful correlation exercise to plot different measured discharge data against the actual rating curve. Measured data from the same stream are shown in Table 5.

These data can then be plotted in the prior duration curve graph. This will make it possible to analyse any changes, other than possible errors (between 1 and 5 percent) in data acquisition.

The data can also be analysed in some other format. The relation between the calculated discharge and the measured discharge can be analysed (Figures 12 and 13). The calculated discharge is based on the application of the formula derived from the H–Q relation.
Annex 3: Discharge calculation

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Flow duration curve

The flow duration curve (FDC) is a cumulative frequency curve that shows the percentage of time in which specified discharges were equalled or exceeded during a given period. It combines in one curve the flow characteristics of a stream throughout the range of discharge, without regard to the sequence of occurrence. If the period on which the curve is based represents the long-term flow of a stream, the curve may be used to predict the distribution of future flows for water use purposes (see Figure 15).

The FDC is a very useful tool for assessing the overall historical variation in flow and the persistence of low-flow events.

The FDC has a wide range of applications including:
- setting river flow objectives;
- scenario evaluation (with respect to the impact of artificial influences such as water abstraction or effluent releases);
- hydropower assessment;
- the evaluation of sediment or contaminant loads; and
- structure design (e.g., a structure can be designed to perform well within some range of flows, such as those exceeded between 20 and 80 percent of the time, or such that it does not alter the low-flow regime).

The FDC also shows the percentage of time that the flow in a stream is likely to equal or exceed some specified value of interest. For example, it can be used to show the percentage of time in which river flow can be expected to exceed a design flow of some specified value (e.g., 20 m³/s), or to show the discharge of the stream that occurs or is exceeded for some percentage of the time (e.g., 80 percent of the time).

The shape of a flow duration curve in its upper and lower regions is particularly significant for evaluating the stream and basin characteristics (Figure 14).

The shape of the curve in a high-flow region indicates the type of flood regime the basin is likely to have, while the shape of the curve in a low-flow region characterises the ability of the basin to sustain low flows during dry seasons.

A very steep curve (high flows for short periods) would be expected for rain-caused floods in small watersheds. The regulation of floods with reservoir storage will generally result in a much flatter curve near the upper limit.

In the low-flow region, an intermittent stream would exhibit periods of no flow, whereas a very flat curve indicates that moderate flows are sustained throughout the year due to natural or artificial streamflow regulation, or due to a large groundwater capacity that sustains the base flow to the stream.

The length and timing of the period of record can alter the FDC. Longer periods of records provide FDCs that better represent temporally averaged conditions within a watershed. If shorter periods are used, extreme climatic condi-
Flow duration curve graph

To establish representative low flows and floods (high flows) for a river course, technicians analyse the frequency of daily flows in the form of a flow duration curve. Annex 2 shows how to proceed with data analysis and how to produce a flow duration curve in an Excel environment.

Bibliography


The regional project **Sustainable Use of Transboundary Water Resources and Water Security Management** (WATER SUM) addresses water-related challenges and promotes regional cooperation in the Middle East and North Africa (MENA) through two project components: Water Resources Management Good Practices and Knowledge Transfer (WATER PORT); and Water Security (WaSe). The WATER PORT component focuses on building skills and transferring knowledge on integrated water resources management in order to promote sustainable development and climate adaptation. The WaSe component supports the introduction of local water security action plans to help communities withstand asset scarcity and tackle environment-related conflicts.

The overall objective of the WATER SUM project is to promote and enhance the sustainability of managing water resources in beneficiary countries in the MENA region in order to halt the downward spiral of poverty and to reduce biodiversity loss and environmental degradation. The main expected impact is institutional and behavioural change in water governance and utilisation patterns. This will be achieved through the successful transfer of knowledge and skills to all participating actors in the water management arena. Additional impacts related to improving water security are also significant in terms of overall environmental security. It is therefore vital to build partnerships in order to address environmental asset scarcity, environmental risks or adverse changes, and environment-related tensions or conflicts, as this is the most effective means for delivering development and conservation targets to local communities and beyond.

The WATER SUM project brings high added value, as it provides beneficiary countries with a structured opportunity to boost their development, share new methods for improved water management, improve planning at all levels of governance, and address unemployment and poverty.

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The REC is an international organisation with a mission to assist in addressing environmental issues. The REC fulfils this mission by promoting cooperation among governments, non-governmental organisations, businesses and other environmental stakeholders, and by supporting the free exchange of information and public participation in environmental decision making.

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