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Supporting monitoring, assessment and information-sharing in transboundary basins

Draft Updated Strategies for Monitoring and Assessment of Transboundary Rivers, Lakes and Groundwaters

Summary and proposed action

At its ninth session (Geneva, 29 September – 1 October 2021) the Meeting of the Parties to the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention) entrusted the Working Group on Monitoring and Assessment to update the *2006 Strategies for Monitoring and Assessment of Transboundary Rivers, Lakes and Groundwaters* as a global edition, as part of the activities foreseen in the programme of work for 2022–2024 for *Programme area 2: Supporting monitoring, assessment and information sharing in transboundary basins* (ECE/MP.WAT/63/Add.1, forthcoming).

The present document includes the draft of the updated Strategies. Its earlier version was prepared by the secretariat in consultation with the lead Parties (Finland and Senegal) based on the written consultations before and discussion at the Expert Meeting on Monitoring, Assessment and Data Exchange (1 April 2021), as well as the inputs gathered during the Global Workshop on Exchange of Data and Information in Transboundary Basins (4–5 December 2019) and the fifteenth meeting of the Working Group on Monitoring and Assessment (6 December 2019). It was then discussed at the Expert Meeting on Monitoring, Assessment and Data Exchange (13-14 April 2022) and revised based on feedback provided by experts during and after the meeting.

The changes made to the 2006 Strategies include the following:

- (a) Description of the procedures for data management and data exchange are extended;
- (b) More attention is given to sustainability aspects of monitoring including financing and the legal basis;
- (c) The differences in monitoring between rivers, lakes and groundwaters are included in annexes;
- (d) The original focus on the ECE region has been extended to cover aspects worldwide;
- (e) New definitions and references have been added;
- (f) A more explicit and stronger link is made between water quality, groundwater and freshwater ecosystems and their ecology;
- (g) Stronger emphasis is put on joint design of monitoring networks and joint sampling campaigns;

- (h) More emphasis is put on inclusiveness (gender, vulnerable groups, etc.) and participation of all stakeholders, as well as on the need of capacity development at national and transboundary levels;
- (i) New technologies and methodologies relevant for monitoring that have emerged after 2006 are described;
- (j) The description of relevant international programmes and information sources has been updated and moved to the Annex.

The Working Groups are invited to review and comment on the text in the present document and:

- (a) Invite countries and organizations to provide written comments on the draft of updated Strategies to the Water Convention secretariat by 31 August 2022;
- (b) Entrust the secretariat, in consultation with the lead Parties, with the task of integrating comments received, finalizing the publication by editing, translating and printing it in Arabic, English, French, Russian and Spanish.

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1. Introduction

Information based on well-organized monitoring programmes is the key prerequisite for accurate assessments of the status of water resources and the magnitude of water problems. These assessments are essential for preparing proper policy actions at the local, national and transboundary levels to achieve national and transboundary goals and targets as well as those of the 2030 Agenda for Sustainable Development. Moreover, integrated water resources management in transboundary basins shared by two or more countries calls for comparable information. There is a need for a common basis for decision-making, which requires harmonized and comparable assessment methods and data management systems as well as uniform reporting procedures. Data and information exchange, wide accessibility, fair and just sharing of open data and information, and joint monitoring and assessment also play an important role in building trust, thus facilitating cooperation and conflict avoidance.

This central role of data and information exchange in ensuring effective transboundary water cooperation has been recognized in the methodology for calculation of the SDG indicator 6.5.2 which measures the proportion of transboundary basin area with an operational arrangement for water cooperation. The existence of *at least annual exchanges of data and information* is among the four criteria for an arrangement to be considered operational.¹ However, the outcomes of the 2020 monitoring exercise under SDG indicator 6.5.2 and under the Water Convention show that joint monitoring and exchange of data and information in transboundary river, lake and aquifer basins still represent a challenge for many countries.²

This publication explains the key principles of and approaches to monitoring and assessment of transboundary waters and describes strategies for monitoring and assessing these waters. It highlights areas of interest to policy and decision makers and provides ground rules for water managers involved in or responsible for establishing and carrying out cooperation between riparian countries, as well as for representatives of joint bodies.

The publication stresses the underlying legal, administrative and financial aspects of monitoring and assessment and discusses the constraints on and opportunities for cooperation. It draws on the experience gained with the implementation of pilot projects and other experience gained in monitoring, assessment and data exchange of transboundary rivers, lakes and groundwaters under the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes³ (Water Convention) and proposes step-by-step approaches for development of monitoring, assessment and data exchange that take into account the available human and financial resources, including in countries with a challenging economic situation.

This publication builds on the 2006 Strategies for Monitoring and Assessment of Transboundary Rivers, Lakes and Groundwaters⁴ and the UNECE Guidelines on monitoring and assessment of transboundary rivers⁵, groundwaters⁶ and lakes⁷ developed under the Water Convention as well

¹ UN-Water, 2020. Step-by-Step Monitoring Methodology for SDG Indicator 6.5.2. Available at <https://www.unwater.org/publications/stepstep-methodology-monitoring-transboundarycooperation-6-5-2/> .

² <https://www.unwater.org/publications/progress-on-transboundary-water-cooperation-652-2021-update/>

³ <http://www.unece.org/env/water/>

⁴ https://unece.org/DAM/env/water/publications/assessment/StrategiesM_A.pdf

⁵ https://unece.org/DAM/env/water/publications/assessment/guidelines_rivers_2000_english.pdf

⁶ <https://unece.org/DAM/env/water/publications/assessment/guidelinesgroundwater.pdf>

⁷ <https://unece.org/DAM/env/water/publications/assessment/lakesstrategydoc.pdf> and at <https://unece.org/DAM/env/water/publications/assessment/lakestechnicaldoc.pdf>

as a review of other pertinent international guidance⁸ performed to assess the pertinence of the 2006 Strategies. In the annexes, an overview is provided of specific aspects of, respectively, groundwater, lakes and river monitoring.

Transboundary estuaries and other transitional waters (such as lagoons, deltas, and coastal lakes) are not explicitly included in this publication. They should nevertheless be considered within the framework of the Water Convention⁹. The general principles and approaches as described in this publication also apply for transboundary estuaries and other transitional waters. The specifics of estuaries, including tidal movements, hydrological regime, and salinity, require a targeted approach for the monitoring practice and are described in Annex 4, where further reference is given.

⁸ Outlook for developing monitoring cooperation and exchange of data and information across borders: Background paper to the Global workshop on exchange of data and information and to the fifteenth meeting of the Working Group on Monitoring and Assessment under the Water Convention (Geneva, 4–6 December 2019), ECE/MP.WAT/WG.2/2019/INF.1, http://www.unece.org/fileadmin/DAM/env/documents/2019/WAT/12Dec_4-5_Global_Workshop_on_Data_Exchange/Background_document_on_exchange_of_data_and_information_01122019_rev.pdf

⁹ Also see <https://unece.org/DAM/env/water/meetings/wgma/doc/wgma-2002-7.pdf> and [https://circabc.europa.eu/sd/a/63f7715f-0f45-4955-b7cb-58ca305e42a8/Guidance%20No%207%20-%20Monitoring%20\(WG%202.7\).pdf](https://circabc.europa.eu/sd/a/63f7715f-0f45-4955-b7cb-58ca305e42a8/Guidance%20No%207%20-%20Monitoring%20(WG%202.7).pdf)

2. Basic principles and approaches

2.1. Monitoring and assessment

The ultimate goal of monitoring¹⁰ is to provide the information needed for planning, decision-making and operational water management at the local, national and transboundary levels. Monitoring programmes are also fundamental to the protection of human health and the environment in general. Monitoring cannot be separated from assessment¹¹ as the assessment translates the monitoring results into information of the state of a water and its changes. Assessment provides basis for describing the direction of the change and can be related to environmental targets or objectives, which can be linked with pressures and impacts (Figure 1). Assessment also includes the boundary conditions and the broader social and environmental context determining the state of the environment.

A surface water or groundwater basin's various uses and functions and related water management issues should be well known, documented and prioritized to build up a useful monitoring and assessment programme. The connections between different water management issues can be clarified through the Driving Forces–Pressures–State–Impact–Responses (DPSIR) framework (Figure 1).

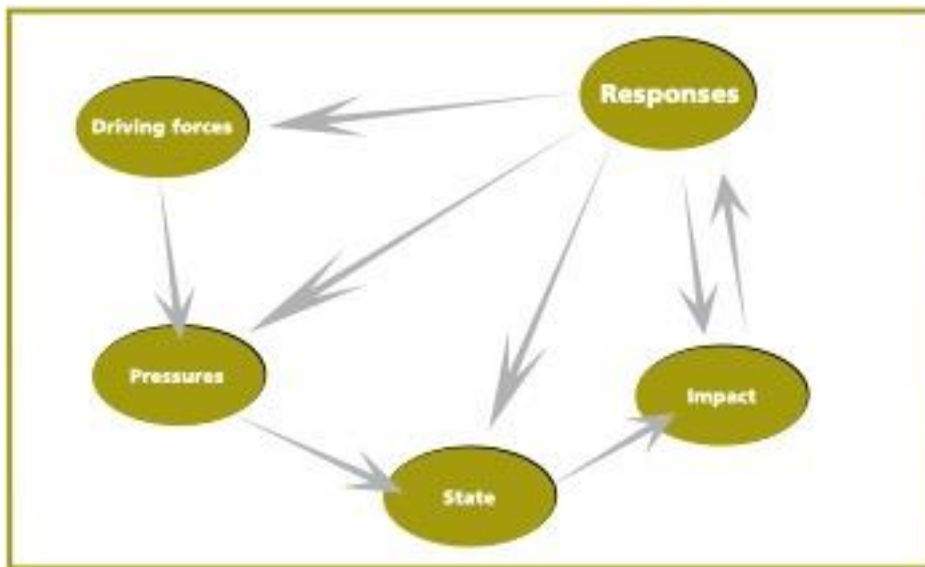


Figure 1: The Driving Forces–Pressures–State–Impact–Responses (DPSIR) framework¹²

The DPSIR framework assumes that social, economic and environmental systems are interrelated. These links are illustrated conceptually by driving forces of environmental change, which create pressures on the environment. These in turn affect the state of the environment. The subsequent changes in status, or “impacts”, include impacts on ecosystems, economies and communities. The negative impacts will eventually lead to responses by society, such as the development of policies for basin protection. If a policy has the intended effect, its implementation will influence the driving forces, pressures, status (state) and impacts.

¹⁰ Monitoring is the systematically scrutinizing and checking with a view to collecting data (<https://www.wef.org/resources/for-the-public/public-information/glossary/>).

¹¹ Assessment is the determination of the sources, extent, dependability and quality of water resources, and of the human activities that affect those resources, for their utilization and control (<https://community.wmo.int/activity-areas/water-resources-assessment>).

¹² EEA, 1998. Europe's environment: the second assessment. Elsevier Science Ltd., Oxford, UK.

The analysis of information needs is the most critical step in developing a successful, tailor-made and cost-effective monitoring programme. In general, information is needed on each of the elements of the DPSIR framework.

Monitoring is usually understood as a process of repetitive measurements, other observations or data acquisitions, for various defined purposes, of one or more elements of the environment according to pre-arranged schedules in space and time, using comparable methodologies for environmental sensing and data collection. For comparability over time, as far as possible, measurements should be made, and samples collected at the same locations at regular time intervals.

Monitoring enables assessments of the current state of water quantity and quality and their variability in space and time. Often such assessments are appraisals of the hydrological, morphological, physicochemical, chemical, biological and/or microbiological conditions in relation to reference conditions, human health effects and/or the existing or planned uses of water. Such reference conditions comprise natural variability geophysical and geochemical processes that may influence concentrations of specific variables.

A specific purpose of monitoring is to support decision-making and operational water management in critical situations. In critical hydrological situations, such as floods, ice drifts and droughts, timely and reliable hydro-meteorological data are needed, which often requires telemetric systems to transmit data continuously. When pollution events occur, reliable data are needed, which may require early warning systems to signal when critical pollution levels are exceeded or toxic effects occur. In these cases, models can often support decision-making.

In developing and operating a monitoring system, it is essential that the system is gender responsive, inclusive, and that the data and information are accessible. Identifying the factors that contribute to the inclusion or exclusion of women and men belonging to different social, cultural or ethnic groups, such as indigenous people, and the ways in which they interact with water resources for different uses, could improve the provision, management and conservation of the world's water resources for the benefit of all. Representation of wide groups of stakeholders in all steps of the monitoring cycle is a basic starting point to this end.¹³ Moreover, gender-disaggregated statistics are essential to elucidate the circumstances, life situation and needs of men and women.¹⁴

For transboundary waters, information is often gathered from the national monitoring systems (which are established and operated according to national laws and regulations and international agreements), rather than from monitoring systems specifically established and operated by joint bodies. Thus, the national legislation as well as obligations under international agreements and other commitments should be carefully examined in preparation for establishing, upgrading, and running these systems.

2.2. Basin approach

The basin forms a natural unit for integrated water resources management in which rivers, lakes and groundwaters interact with other ecosystems. A basin means the area of land from which all surface runoff flows through a sequence of streams, rivers, groundwater bodies and possibly lakes into the sea at a single river mouth, estuary, lagoon, or delta (Figure 2), or the area of land from

¹³ See, e.g., the report Gender-responsive indicators for water assessment, monitoring and reporting – available at <https://unesdoc.unesco.org/ark:/48223/pf0000367971.locale=en>

¹⁴ See, e.g., <https://www.includegender.org/toolbox/map-and-analyse/gender-statistics/>

which all surface runoff ends up in another final recipient of water, such as a lake or a desert. The whole basin should therefore be considered when developing a monitoring system.

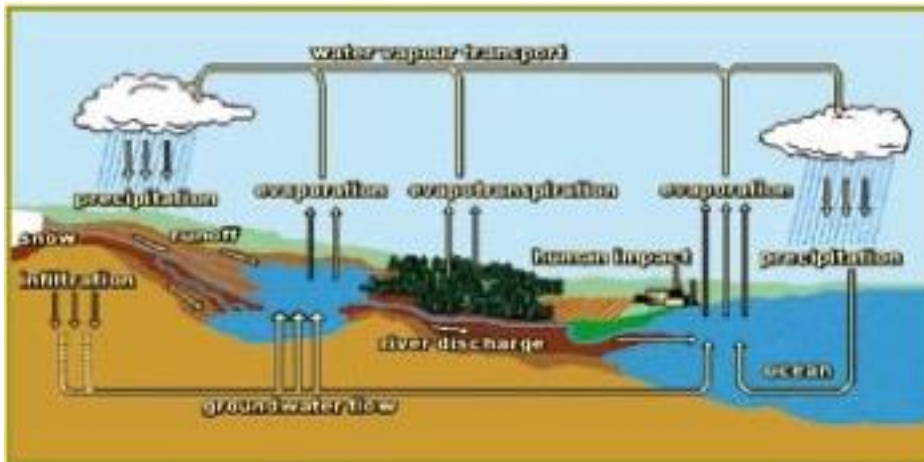


Figure 2: The key elements of the hydrological cycle of a basin

As basins usually stretch over different administrative and geographical units and State borders, cooperation between competent actors is needed. These actors include environmental and water agencies, hydro-meteorological services, geological surveys, public health institutions and water laboratories. They also include research institutes and universities engaged in methodological work on monitoring, modelling, forecasting and assessments. The knowledge of the local and indigenous people groups should also be incorporated as a knowledge source in the monitoring systems.¹⁵ Such cooperative arrangements and institutional frameworks greatly influence the efficiency of monitoring and assessment. Concerted action plans as required under the Water Convention and water resources management plans are an important basis for specifying information needs for monitoring and assessment.

The level of detail that monitoring and assessment can provide depends on the density of the network, the frequency of measurements/observations, the size of the basin and/or the issues under investigation. For example, when a measuring station at the outlet of a (sub-)basin reports water-quality changes, often a more detailed monitoring network is needed to reveal the sources, the causal agents and the pathways of pollutants. The interaction between surface waters and groundwaters may also be different in the upper and lower parts of the basin. In these cases, information is needed for smaller sub-basins. Monitoring networks, the frequency of measurements and variables as well assessment methodologies should be adapted to these conditions. To facilitate this, a conceptual model of the basin should be developed so that the interactions between surface water and groundwater and between water quantity and quality can be taken into account.

2.3. Different purposes

Information based on well-organized monitoring programmes that cover the complexity of issues (Figure 3)¹⁶ is a prerequisite for accurate assessments of the status of water resources and the magnitude of water problems. Such assessments are essential for preparing proper policy actions at the local, national and transboundary levels. At the transboundary level there is a need for a common basis for decision-making, which requires harmonized and comparable data and

¹⁵ https://en.unesco.org/sites/default/files/links_indigenous_tracking_20210913.pdf

¹⁶ INBO 2018. The handbook on water information systems administration. Processing and exploitation of water-related data. <https://www.inbo-news.org/en/file/314142/download?token=5uPk1dZ9>

information. Indeed, water resources management in transboundary basins requires sharing data and information that meets the expectations of stakeholders for various activities. Figure 3¹⁷ outlines some of the main domains requiring access to water-related data.

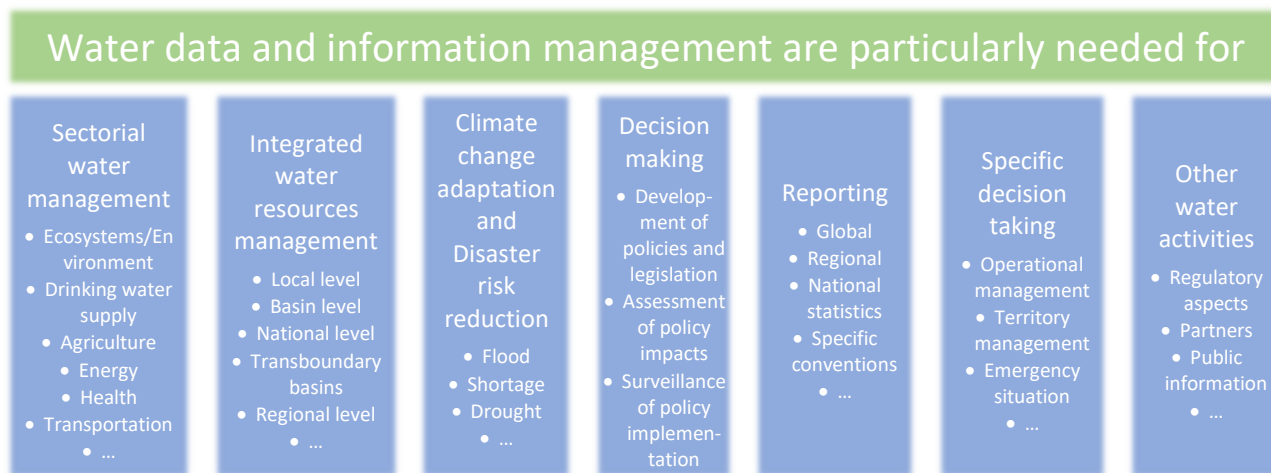


Figure 3: Different purposes for water data

The regular exchange of data and information is also fundamental for establishing good cooperation between countries. This is particularly important for routine water resource operational management such as water sharing for irrigation, natural living resources (e.g., migratory fish and other assets based on biodiversity), as well as for medium or long-term basin planning, with monitoring of the programme of measures and investments. Unfortunately, in many cases, data collection processes and data exchange are limited: when data are available, existing datasets are usually fragmented, incomplete, dispersed and heterogeneous. In developing and maintaining monitoring and data exchange systems it is essential that the whole information system is supported by an appropriate institutional framework. This includes that the responsibilities of each actor are clear and that there is sustainable funding and resources. Especially in a transboundary setting assigning and sharing responsibilities is central.

2.4. Benefits of joint monitoring

Joint monitoring includes substantial benefits for countries. During the second reporting exercise under the Water Convention in 2020 countries were asked to report on the main achievements they experienced in relation to joint monitoring. A range of benefits and achievements was mentioned including:

- Mutual support in establishing a monitoring system, like developing joint approach for future proposal of measures, optimization of activities, joint capacity building, implementing a shared database and drafting joint studies;
- Agreement on and improvement of monitoring parameters and methods, and harmonisation of results from chemical, ecological and biological analysis of water from agreed monitoring stations;

¹⁷ Modified from INBO 2018. The handbook on water information systems administration, processing and exploitation of water-related data, available at <https://www.inbo-news.org/en/file/314142/download?token=5uPk1dZ9>

- Improved basin-wide, transparent, harmonized, 'neutral' and reliable information and data on the state of the environment leading to greater technical and scientific understanding of the entire basin as the basis for better management of water bodies;
- Improved forecasting, impact assessment and dissemination of results for better decision-making;
- Development of regular common reports, like impact studies and State of the Basin Reports;
- Improved early warning through the availability of continuous monitoring results to detect contaminations in time for intervention, for flood forecasting and disaster risk management, including successful coordination and cooperation during flooding events;
- Improved understanding of the distribution of the basin's water resources and water balances, enabling setting environmental flows and better control and operational rules for the basin and sub-basins and efficient water supply to parties;
- Shared concepts of pressures and impacts providing a common ground for cooperation, offering a platform for disputes settlement and improved trust and confidence among riparian states, their institutions, citizens and indigenous people, as well as enhance cooperation

3. Legislation and commitments

Multilateral environmental agreements, including various Conventions and Protocols, and bilateral and multilateral transboundary water agreements contain obligations for countries to monitor and assess waters and to report, as appropriate, to a specific body, such as an international commission, secretariat or organization. Ideally, these obligations should be introduced to the national legislation to steer the activities in national competent bodies.

A legal framework at national and basin level is imperative to set up and maintain a transboundary monitoring and assessment system. In addition, national legislation should set out obligations and responsibilities for relevant agencies, such as hydro-meteorological services, environmental and health agencies, geological surveys and operators of water regulation structures and industrial installations to monitor and assess various components of the environment and report on the results.

This chapter refers to several global and regional instruments dealing with environmental data and information, among others.

3.1. Global instruments

3.1.1. Water Convention

The main goal of the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention)¹⁸ is to prevent, control and reduce any transboundary impacts, which include significant adverse impacts on human health and safety, flora, fauna, soil, air, water, climate, landscape and historical monuments or other physical structures. The Convention is one of the most essential legal instruments for the monitoring and assessment of transboundary waters.

In defining and specifying information needs, establishing monitoring systems and assessing the status of waters, it should be noted that the Convention requires the setting of emission limits for discharges from point sources on the basis of the best available technology (BAT). It also requires authorizations for wastewater discharges and the application of at least biological or equivalent processes to treat municipal wastewater.

The Convention calls for best environmental practices (BEP) to reduce the input of nutrients and hazardous substances from agriculture and other diffuse sources. In addition, Parties must define water-quality objectives for the purpose of preventing, controlling and reducing transboundary impacts.

The Convention requires the establishment and implementation of joint programmes for monitoring the conditions of transboundary waters as well as transboundary impact. It also requires joint or coordinated assessments of the conditions of transboundary waters at regular intervals and exchange of data and information.

Obligations relating to the monitoring and assessment of specific basins that stem from bilateral or multilateral agreements should be in line with the requirements of the Water Convention. In particular, joint bodies – any bilateral or multilateral commission or other appropriate institutional arrangements for cooperation between Riparian Parties – have a specific role in monitoring and assessment.

¹⁸ https://unece.org/sites/default/files/2021-04/ECE_MP.WAT_41.pdf

3.1.2. Watercourses Convention

The 1997 Convention on the Law of the Non-navigational Uses of International Watercourses¹⁹ (Watercourses Convention) aims at sustainable utilization of international watercourses in an equitable and reasonable manner. In general, Parties to the Watercourses Convention have the obligation to cooperate and not to cause significant harm. Pursuant to this, Parties must exchange data and information on the condition of the watercourse as well as on planned measures on a regular basis and on request of another riparian Party.

The Watercourses Convention and the Water Convention are fully compatible and there is no contradiction between the two. A country can be a Party to both Conventions.

3.1.3. Other global instruments

Legal obligations regarding the monitoring and assessment of transboundary waters also arise from other international legal instruments, such as the Ramsar Convention on Wetlands²⁰, the Convention on Biological Diversity²¹ or the Convention to Combat Desertification²².

3.2. Regional instruments

3.2.1. Protocol on Water and Health

Under the Protocol on Water and Health²³ to the 1992 Water Convention, effective systems for monitoring and assessing situations likely to result in outbreaks or incidents of water-related disease and for responding to them or preventing them should be established. This may include inventories of pollution sources, surveys on high-risk areas for microbiological contamination and toxic substances, and reporting on infectious and other water-related diseases. The Parties must also develop integrated information systems to handle information about long-term trends in water and health; current concerns, past problems and successful solutions; and the provision of such information to the authorities. Moreover, comprehensive national and/or local early warning systems are to be established, improved or maintained.

3.2.2. Industrial Accidents Convention

The 1992 Convention on the Transboundary Effects of Industrial Accidents²⁴ is designed to protect human beings and the environment against industrial accidents by preventing them as far as possible, by reducing their frequency and severity and by mitigating their effects. Through prevention, preparedness and response to industrial accidents, the Convention supports disaster risk reduction. The UNECE Industrial Accidents Notification System comprises a network of points of contact and enables prompt notification of all potentially affected countries in the event of a major accident with transboundary effects, including in the cases of accidental pollution on water bodies.

¹⁹ https://treaties.un.org/doc/Treaties/1998/09/19980925%2006-30%20PM/Ch_XXVII_12p.pdf

²⁰ <http://www.ramsar.org>

²¹ <https://www.cbd.int/convention/>

²² <http://www.unccd.int>

²³ <https://unece.org/DAM/env/documents/2000/wat/mp.wat.2000.1.e.pdf>

²⁴ https://unece.org/fileadmin/DAM/env/documents/2017/TEIA/Publication/ENG_ECE_CP_TEIA_33_final_Convention_publication_March_2017.pdf

3.2.3. Aarhus Convention

The Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters ²⁵ stipulates, inter alia, that any environmental information held by a public authority must usually be provided when requested by a member of the public. The scope of information is quite broad, including information on water and human health and safety. Public authorities may impose a charge for supplying information provided the charge does not exceed a “reasonable” amount. There is an obligation to progressively make environmental information publicly available via electronic databases. The Convention specifies certain categories of information (e.g., state of the environment reports) that should be made available in this form.

The Protocol on Pollutant Release and Transfer Registers (PRTRs) ²⁶ to the Aarhus Convention requires Parties to establish and maintain a publicly accessible national PRTR with information on releases of pollutants in the air, water and land. The information contained in the PRTR is to be supplied through mandatory periodic reporting by the owners or operators of polluting facilities. The Protocol requires that PRTRs also progressively contain information on pollution from diffuse sources, such as from agriculture to water.

3.2.4. Escazú Agreement

The Regional Agreement on Access to Information, Public Participation and Justice in Environmental Matters in Latin America and the Caribbean ²⁷, better known as the Escazú Agreement, is an international treaty signed by 24 Latin American and Caribbean nations concerning the rights of access to information about the environment, public participation in environmental decision-making, environmental justice, and a healthy and sustainable environment for current and future generations.

The Escazú Agreement is the first international treaty in Latin America and the Caribbean concerning the environment. It aims to provide full public access to environmental information, environmental decision-making, and legal protection and recourse concerning environmental matters. It also recognizes the right of current and future generations to a healthy environment and sustainable development.

3.3. Other international commitments

Commitments on monitoring and data exchange are present in many other regional, subregional, basin-wide and bilateral agreements on transboundary cooperation. This section will not go into the individual basin or bilateral agreements but describes a few international commitments that cover water management at a regional or subregional scale.

3.3.1. Amazon Cooperation Treaty Organization (ACTO)

The Amazon Cooperation Treaty Organization (ACTO), an intergovernmental organization formed by the eight Amazonian countries: Bolivia, Brazil, Colombia, Ecuador, Guyana, Peru, Suriname, and Venezuela, developed a strategic agenda for conservation and sustainable use of renewable natural resources and sustainable development. In this Amazon Strategic Cooperation Agenda ²⁸, under ‘Knowledge management and information sharing’ the exchange of information, knowledge and technology on all the thematic areas including water resources is stressed, under the principles of

²⁵ <http://www.unece.org/env/pp/welcome.html>

²⁶ <https://unece.org/env/pp/protocol-on-prtrs-introduction>

²⁷ https://repositorio.cepal.org/bitstream/handle/11362/43583/1/S1800428_en.pdf

²⁸ <http://otca.org/en/wp-content/uploads/2021/01/Strategic-Agenda-of-Amazon-Cooperation.pdf>

solidarity, reciprocity, respect, harmony, complementarity, transparency, equilibrium and equitable conditions. The Amazon Regional Observatory ²⁹ fosters the flow of information between institutions and intergovernmental authorities of the Member Countries.

3.3.2. EU legislation

The legislation of the European Union is a major tool for defining how surface waters and groundwaters should be used, protected and restored in the EU region. The key directive concerning monitoring is Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for European Community action in the field of water policy, hereinafter referred to as the Water Framework Directive (WFD) ³⁰. The WFD provides the framework for the protection of surface waters, transitional waters, coastal waters and groundwaters in the EU area. The main aims of the WFD are to prevent further deterioration of and protect and enhance the status of aquatic ecosystems, to promote sustainable water use, and to mitigate the effects of floods and droughts. The environmental objective is to prevent deterioration of the status of all waters and to achieve good ecological and chemical status for waters by 2027 at the latest.

Within a river basin where use of water may have transboundary effects, the requirements for the achievement of the environmental objectives established under the WFD, and in particular all programmes of measures, should be coordinated for the whole basin. For river basins extending beyond the boundaries of the Community, member States should endeavour to ensure appropriate coordination with the relevant non-member States. The WFD is meant to contribute to the implementation of Community obligations under international conventions on water protection and management, notably the Water Convention. The WFD through its unifying role for many countries, among others through joint River Basin Management Plans (RBMPs), has supported harmonization and intercalibration of approaches, indicators and standards.

The water monitoring system shall be established to provide a coherent and comprehensive overview of the ecological and chemical status of each basin. To address the challenges in a cooperative and coordinated way, member States, Norway and the European Commission agreed on a Common Implementation Strategy. A number of guidance documents ³¹ covering, among other issues, monitoring and public participation were prepared to support the implementation of the WFD.

Underlying the WFD is the Directive on Environmental Quality Standards (Directive 2008/105/EC) (EQSD) ³², also known as the Priority Substances Directive, which also set environmental quality standards (EQS) for the substances in surface waters. The list is regularly updated.

The Drinking Water Directive (Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption) concerns the quality of water intended for human consumption. Its objective is to protect human health from adverse effects of any contamination of water intended for human consumption by ensuring that it is wholesome and clean. In 2020, the Directive ³³ was revised reinforcing water quality standards, including emerging pollutants and introducing a preventive approach that favours actions to reduce pollution at its source.

²⁹ <https://oraotca.org/en/>

³⁰ <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32000L0060&qid=1643807539361>

³¹ https://ec.europa.eu/environment/water/water-framework/facts_figures/guidance_docs_en.htm

³² <https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32013L0039>

³³ <https://eur-lex.europa.eu/eli/dir/2020/2184/oj>

The Groundwater Directive (2006/118/EC)³⁴ establishes a regime which sets groundwater quality standards and introduces measures to prevent or limit inputs of pollutants into groundwater. The directive establishes quality criteria that takes into account local characteristics and allows for further improvements to be made based on monitoring data and new scientific knowledge.

Directive 2007/60/EC on the assessment and management of flood risks entered into force on 26 November 2007.³⁵ It aims to reduce and manage the risks that floods pose to human health, the environment, cultural heritage and economic activity. The Floods Directive requires Member States to assess all water courses and coast lines which are at risk from flooding, to map the flood extent and assets and humans at risk in these areas and to take adequate and coordinated measures to reduce this flood risk. The Directive also reinforces the rights of the public to access this information and to have a say in the planning process.

The Directive (EU) 2019/1024 on open data and the re-use of public sector information³⁶ stipulates minimum requirements for EU member states regarding making public sector information available for re-use and provides a common legislative framework for this area

3.3.3. African Ministers Council on Water (AMCOW)

The African Ministers Council on Water (AMCOW) has introduced a harmonized process for monitoring and reporting on water and sanitation targets across several international agreements. A web-based reporting system, Pan-African Water and Sanitation Sector Monitoring and Reporting System (WASSMO)³⁷, supports the process.

The platform aims for a comprehensive and harmonized approach to building monitoring capacity in the region. It provides for reporting on seven themes: water infrastructure for growth; managing and protecting water resources; water supply, sanitation, hygiene and wastewater; climate change and disaster risk reduction (DRR); governance and institutions; financing; and information management and capacity development.

3.3.4. Southern African Development Community (SADC)

The SADC Revised Protocol on Shared Watercourses³⁸ was developed in 2000. The overall objective of this Protocol is to foster closer cooperation for judicious, sustainable, and coordinated management, protection and utilisation of shared watercourses and advance the SADC agenda of regional integration and poverty alleviation. It sets the framework for utilization of watercourses shared by two or more SADC member states. The Protocol provides for the establishment of shared Watercourse Institutions that shall provide all the information necessary to assess progress on the implementation of the Protocol.

Under the protocol, Guidelines on Strengthening River Basin Organizations³⁹ were developed. These guidelines, among others, describe the necessity to implement information exchange between the respective governments.

³⁴ <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02006L0118-20140711>

³⁵ <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32007L0060>

³⁶ <https://op.europa.eu/en/publication-detail/-/publication/a6ef4c41-97eb-11e9-9369-01aa75ed71a1>

³⁷ <https://amcow-online.org/initiatives/water-and-sanitation-sector-monitoring-and-reporting-system-wassmo>

³⁸ https://www.sadc.int/files/3413/6698/6218/Revised_Protocol_on_Shared_Watercourses_-_2000_-_English.pdf

³⁹ https://www.sadc.int/files/4513/5333/8265/SADC_guideline_establishment.pdf

3.3.5. Regional seas conventions

Several regional seas conventions ⁴⁰ have protocols concerning assessment and prevention of pollution from land-based sources, as riverine transport can be the major source of pollutants to estuaries and other transitional waters, and the adjacent marine waters. Their activities include obligations and guidelines relevant for monitoring and assessment of transboundary transitional waters, such as monitoring and assessment of pressures, e.g., riverine loading of nutrients and harmful substances, and the environmental state of transitional and coastal waters.

⁴⁰ This refers to, among others, the [Convention for the Protection of the Mediterranean Sea Against Pollution](#) (Barcelona Convention), [Convention for the Protection and Development of the Marine Environment in the Wider Caribbean Region](#) (Cartagena Convention), [Convention for Cooperation in the Protection, Management and Development of the Marine and Coastal Environment of the Atlantic Coast of the West and Central Africa Region](#) (Abidjan Convention), [Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Western Indian Ocean](#) (Nairobi Convention), the [Framework Convention for the Protection of the Marine Environment of the Caspian Sea](#) (Tehran Convention), the [Baltic Marine Environment Protection Commission](#) (Helsinki Commission - HELCOM) and the [Convention for the Protection of the Marine Environment of the North-East Atlantic](#) (the 'OSPAR Convention').

4. Establishing the institutional framework

4.1. Institutional arrangements at the national level

Suitable institutional arrangements at the national and local levels are a precondition for monitoring and assessment of transboundary waters, to ensure cooperation among various governmental entities, the private sector and others. In making these arrangements, it is important to note that the responsibility for groundwater monitoring and assessment with regard to water quality and quantity may lie with geological survey organizations rather than environmental or water agencies, while environmental agencies may provide data on ecological and biophysical parameters of waterbodies (including ecological status, biodiversity, hydro-morphology, land degradation, waste, etc.). Ample attention should be given to capacity development of all individuals involved.

Coordination of the monitoring and assessment at national level between the various organizations involved in water management, including basin agencies, is necessary to ensure effective and efficient water management. Moreover, cooperation among water, environmental and health authorities is needed to ensure the collection and use of data related to human health and safety.

Hydro-meteorological services play an essential role in providing water quantity data and early warning information for extreme hydrological events. Organizations which operate response systems for emergencies involving water regulation structures and industrial plants are important partners in providing data to mitigate the adverse impacts of failures of or other accidents at such installations on transboundary waters. Industrial enterprises that monitor their own water abstractions and wastewater discharges provide data for compliance purposes. Assessment of watercourses also requires socio-economic data, including population and economic statistics, which are collected by statistical offices. In many instances, it is necessary to seek expertise from research institutions, universities or the private sector.

4.2. Institutional arrangements at the transboundary level

Functioning institutions and suitable institutional arrangements for monitoring and assessment at the national and local levels are a prerequisite for international cooperation, particularly in connection with the work of joint bodies, which includes the implementation of their monitoring-and-assessment-related tasks. The joint body should function as a forum for the exchange of information and data, including on planned measures and activities, and for the harmonization of monitoring approaches⁴¹. Particular efforts should be made to build and strengthen their capacity.

Riparian countries may decide to establish a specific working group under the joint body, in which experts from different disciplines meet regularly to agree upon the implementation of monitoring and assessment activities, including the technical, financial and organizational aspects.

Basic requirements for joint monitoring and assessment that might be set out in a provision of an arrangement, annex or protocol include coordinated or harmonized data gathering and processing methods, databases, digitalization of data, providing access to the information via Internet; compatibility of laboratories taking part in the monitoring; joint research and studies, exchange of knowledge and use of models; monitoring arrangements (regulations); and coordinated or harmonized monitoring and assessment programmes⁴². In the absence of a joint body, riparian countries can decide to set up an arrangement specifically for monitoring and assessment.

⁴¹ https://unece.org/DAM/env/water/publications/WAT_Joint_Bodies/ECE_MP.WAT_50_Joint_bodies_2018_ENG.pdf

⁴² https://unece.org/sites/default/files/2021-11/ece_mp.wat_68_eng.pdf

While monitoring systems usually operate at a national level, some do operate at a transboundary level through a basin or sub-basin arrangement. More information about data and information exchange and the role of joint bodies can be found in the reports⁴³ on SDG indicator 6.5.2.

Joint monitoring exercises are a good means to improve harmonisation of information across the riparian countries. Such exercises can be done at intervals and can come on top of the regular national monitoring⁴⁴.

In transboundary monitoring, it is advisable to seek the involvement of border guards to facilitate joint sampling near the borderline, the transport of samples across the border, and timely delivery of samples to laboratories.

4.3. Institutional arrangements related to quality control procedures

Quality control procedures should be set up, as it is essential for ensuring the reliability of information obtained by monitoring. The quality system should be organized around all the elements of the monitoring and assessment cycle, starting with documenting procedures for the specification of information needs and developing an information strategy. Standards, established under the auspices of the International Organization for Standardization (ISO), the European Committee for Standardization (CEN) and other organizations for sample collection, transport and storage, and laboratory analysis, are the basis for the quality system. WMO as a standard setting organization has developed a series of hydro-meteorological guidelines and regulations. Protocols for data validation, storage and exchange as well as data analysis and reporting should be established and documented⁴⁵. Riparian countries should, where appropriate, assign to their joint bodies or through the joint arrangement responsibilities related to quality systems. Transboundary cooperation at the local level should be encouraged and promoted, including direct contacts between laboratories and institutions involved.

As many decision makers are not aware of quality control procedures, it is essential to stress that it is important to strengthen quality assurance in a step-by-step approach: from simple internal quality control measures to overall accreditation, and finally to international standards⁴⁶. Quality management, and connected to that quality assurance and quality control, has four major benefits:

- It enables better management of the process and a more effective organization;
- It leads to employee satisfaction and commitment to the organization;
- It improves the quality of products and services; and
- It improves customer satisfaction and the image of the hydrological services.

Implementation of quality management systems will assist hydrological services in the provision of good management practices and ultimately will enhance confidence in the quality of their data, products and services. The process of quality management is part of the Monitoring and Assessment Cycle (Figure 4) and includes the following elements:

- Definition of the goals (monitoring, management, environmental, etc.);

⁴³ Progress on Transboundary Water Cooperation: Global status of SDG indicator 6.5.2 and acceleration needs, 2021, available at: <https://unece.org/environment-policy/publications/progress-transboundary-water-cooperation-global-status-sdg> and Progress on transboundary water cooperation under the water convention: Second report on implementation of the Convention on the Protection and Use of Transboundary Watercourses and International Lakes, 2017–2020, available at: <https://unece.org/info/publications/pub/360105>

⁴⁴ A good example of a joint monitoring exercise is the Joint Danube Survey (<http://www.danubesurvey.org/jds4/>)

⁴⁵ https://unece.org/DAM/env/water/publications/documents/quality_assurance.pdf

⁴⁶ See, e.g., ISO/IEC/EN 17025 covering general requirements for the competence of calibration and testing laboratories <http://www.fasor.com/iso25>

- Information requirement (including acceptable uncertainty);
- Value chain holistic approach (QM embedded in the whole system, not isolated in the Individual steps);
- Selection of variables to be monitored;
- Processes (including data rescue, data validation);
- Data handling and management; and
- Institutional arrangements in support to QM implementation.

4.4. Frameworks for exchanging and accessing information

According to provisions of the Aarhus Convention and Escazú Agreement, environmental information shall be available to the public. According to the provisions of the Water Convention, riparian countries should give each other access to relevant information on surface water and groundwater quality and quantity. And according to SDG indicator 6.5.2, an operational arrangement between riparian countries requires a regular (at least once per year) exchange of data and information between them (criterion 4).

Arrangements for the exchange of information among riparian countries should be governed by rules jointly agreed by these countries. The arrangements should specify the format and frequency of exchange. Readily available information should be exchanged free of charge. Also, arrangements for the provision of information to the public should be jointly discussed and may include the establishment and maintenance of a joint website.

Where possible, riparian countries could aim towards open data bases following the FAIR-principles (data/outputs findable, accessible, interoperable and reusable (FAIR)) ⁴⁷.

Information is based on aggregated data. It is important in exchanging information that the underlying data are available and accessible for reasons of transparency. An open data policy is therefore one of the good practices put forward by WMO ⁴⁸.

⁴⁷ <https://www.go-fair.org/fair-principles/>

⁴⁸ Also see <http://www.bom.gov.au/water/about/publications/document/Good-Practice-Guidelines-for-Water-Data-Management-Policy.pdf>

5. Securing funding for monitoring and assessment

In securing funding, distinction should be made between the development of a monitoring system that may involve other funding sources, like loans, than those for maintenance and operation of the system. It should be noted that much information can be collected at limited cost through a step-by-step approach (also see Chapter 6).

Sustainable financing of monitoring systems is needed to be able to identify trends and changes over time and therefore to single out effects of policies and measures. Joint bodies can in some settings be uniquely positioned to support transboundary activities, particularly information collection and institutional strengthening actions. Infrastructure assets, like monitoring stations, are typically (although not always) developed and managed at the national level, even when the data are shared by more than one country. That said, some activities can be implemented through national and transnational actions, such as the installation and management of monitoring stations for weather information and analysis. In such a case the physical investments may be made on a national level, while a joint body can provide capacity building for data collection and management, the institutional home for a database, analytical services, and information dissemination.

Monitoring and assessment of water quality and quantity require adequate resources. Therefore, those who carry out monitoring and assessment need to be able to convincingly demonstrate both the benefits of monitoring for integrated water resources management and the possible costs, in terms of environmental degradation and other impacts, of not monitoring. This is particularly crucial for countries in which monitoring activities still seem to be insufficiently funded.

As each basin is different, joint bodies need to identify the most suitable role in supporting financing of the monitoring system for their basin. The costs of monitoring should be estimated before monitoring programmes begin, or when major revisions are planned. If the information needs are well defined, the estimate can be rather detailed. Monitoring costs can be divided into investment costs and operation costs. Typically, the costs include the following components:

- Network administration, including design and revision;
- Capital costs of monitoring and sampling equipment, automatic measuring stations and data transmission systems, construction of observation boreholes or surface water sampling sites and gauging stations, transport equipment, data processing hardware and software;
- Labour and other operating costs of visits to monitoring locations, sampling, field analysis of water-quality variables and field measurements of water levels and discharge characteristics;
- Maintenance of monitoring stations (e.g., boreholes, automatic stations);
- Development and maintenance of databases;
- Operating costs of online data transmission systems (e.g., water levels, accidental water pollution);
- Labour and other operating costs of laboratory analyses;
- Labour and associated operating costs of data storage and processing;
- Regular training of staff, including for new instruments or systems;
- Costs for quality assurance like intercalibration exercises and general quality management;
- Assessment and reporting (including joint work for transboundary waters); production of outputs, including geographic information systems (GIS) or presentation software and report printing costs.

The costs associated with administration as well as assessment and reporting are largely fixed and relatively independent of the extent of the system. In contrast, the costs of other activities are strongly influenced by the number and types of sampling points, the frequency of sampling and the range of variables to be analysed. The number of sampling points can be multiplied with frequency and variables to obtain rough cost estimates.

Because of the continuous character of monitoring, a long-term commitment to funding is crucial to ensure the sustainability of monitoring and assessment activities. This means that funding should come mainly from the State budget. Water users, such as municipalities, water and waste utilities, factories, farmers and irrigators, should contribute to funding the programmes. It may be possible to raise funds by using part of the income from water abstraction fees or by invoking the polluter pays principle. Donor-funded projects concerning transboundary watercourses should be coordinated with national authorities to ensure the continuity of monitoring activities which have been established in a specific project.

It is essential that monitoring and assessment programmes for transboundary waters be part of the national monitoring programmes of the riparian countries. These countries should take responsibility for all costs arising on their own territory. Moreover, the riparian countries should jointly decide on funding principles and make clear agreements regarding the funding of specific joint tasks.

The report *Funding and Financing of Transboundary Water Cooperation and Basin Development*⁴⁹ provides an overview of possible sources for funding transboundary water cooperation. Funding sources include public funding through (regional) taxes, user/polluter fees, management and administration fees, loans and grants, technical assistance and climate funds. Private funding sources are rare. Whereas domestic budgetary resources from riparian states should be the primary financial source to support monitoring, in many instances significant assistance through International Financial Institutions (IFIs) and projects is needed.

When looking at the costs of monitoring and assessment it should be recognized that, when well-designed, the monitoring and assessment system not only provides information relevant for the transboundary cooperation but also provides valuable information for national policymaking.⁵⁰

⁴⁹ <https://unece.org/info/publications/pub/359843>

⁵⁰ See, e.g., <https://www.sdg6monitoring.org/why/> and <https://link.springer.com/article/10.1007/s10113-004-0087-6>

6. Developing step-by-step approaches

6.1. Character of the step-by-step approaches

Monitoring and assessment of transboundary waters have multiple purposes. To make the best use of available resources and knowledge, a step-by-step approach is recommended. This entails identifying and agreeing on priorities for monitoring and assessment and progressively proceeding from general appraisal to more precise assessments and from labour-intensive methods to higher-technology ones. Such a step-by-step approach can also help to specify the information needs and thus focus the assessment activities so that they are as effective as possible.

Developing a step-by-step approach in a transboundary context may also have other implications. It might, for example, mean starting with informal cooperation at an operational level and, as mutual trust increases, lead to more formal agreements and establishment of joint bodies. Experience suggests that it could involve starting with modest objectives – for example, regular exchange of data and information about the sampling methods and instrumentation used. This could lead to jointly agreed measurement and sampling procedures and analytical methodologies, which would pave the way to joint measurements and sampling. The eventual target would be joint data analysis and regular joint assessments backed up by joint monitoring design.

Taking a step-by-step approach could also mean starting with data exchange for stations and sampling points close to the border and then, once this activity is well established, extending it to the whole transboundary basin or aquifer⁵¹. Finally, a step-by-step approach might mean starting with the exchange of information on water status (quality and quantity) and then, as the relationship between riparian countries becomes stronger, sharing information on pressures and driving forces; evaluating the impacts on the main water uses; and considering possible responses – that is, applying the DPSIR framework.

Implementing the recommendations of UNECE Guidelines on monitoring and assessment of transboundary rivers⁵², groundwaters⁵³ and lakes⁵⁴, involves applying the step-by-step approaches promulgated through these guidelines. Attaining the purposes and objectives of monitoring and assessment is like creating a road map to achieving a final goal. It is a way of building “modules” for transboundary water monitoring and assessment, starting with tasks that can be easily accomplished in a given situation. These are followed by tasks that will be carried out later when there are increased human and financial resources, better knowledge and mutual understanding or otherwise improved conditions for transboundary cooperation.

In countries where it is difficult to amend national legislation in the short term, a step-by-step approach could be followed by accepting the use of water-quality objectives or even ecologically based objectives as a basis for the monitoring and assessment work of joint bodies. This could become part of jointly agreed rules or even protocols to bilateral and multilateral agreements, without the need to amend national law.

6.2. Prioritizing monitoring efforts

Identification of the main water functions and uses and the main issues relating to it (see Section 7.2) is needed to determine the most important information needs for water quality and quantity,

⁵¹ An aquifer is a permeable water bearing formation capable of yielding exploitable quantities of water.

⁵² https://unece.org/DAM/env/water/publications/assessment/guidelines_rivers_2000_english.pdf

⁵³ <https://unece.org/DAM/env/water/publications/assessment/guidelinesgroundwater.pdf>

⁵⁴ <https://unece.org/DAM/env/water/publications/assessment/lakesstrategydoc.pdf> and at <https://unece.org/DAM/env/water/publications/assessment/lakestechnicaldoc.pdf>

and the relevant variables requiring monitoring. National surveys and land-use maps can provide a rapid overview of possible pressures in the basin.

By using risk assessment techniques (and recording how these were applied), those responsible for assessments can decide which monitoring activities have the highest priority. This could be done using the concept of “expected damage” – that is, determining what goes wrong when there is insufficient information because of lack of monitoring, or what losses occur when less than optimal decisions are made as a result.

No monitoring programme can measure all the variables at as many sites and as frequently as would be desirable. Therefore, within the monitoring design, risk-based approaches should be used to select variables. For many variables, existing literature on their occurrence in the environment and particularly in freshwater systems and existing information about the potentially polluting activities present in the basin in question can provide guidance in prioritization. Based on their properties, predictions can be made as to which chemicals are most likely to reach surface water and groundwater.

In the case of groundwater, the long-established and widely adopted approach of defining and mapping the vulnerability of aquifers to pollution can be used to prioritize monitoring. Based on the physical and chemical properties of the soil and geological materials above the water table, the potential for pollutants to be retarded and attenuated is evaluated and mapped. Where such maps exist, they can be used to help focus monitoring in areas where groundwater has important uses and where it is most vulnerable.

Risk assessment can also be used to determine whether the chosen monitoring strategy will fully meet the information needs. Statistical modelling to help optimize monitoring design (spatial density and sampling frequency) implies an element of risk analysis. It provides, for example, information on whether the resulting decreased level of information will still meet all previously specified information needs if either density or frequency is reduced.

6.3. Use of models in monitoring and assessment

Models (numerical, analytical, or statistical) can play several roles in monitoring and assessment. For monitoring, models can be used to calculate water quality and quantity at certain locations, thus enabling reducing the monitoring efforts. Regular calibration with real measurements will remain necessary to calibrate the model. For assessment purposes, computer models of the rivers and surrounding areas, linked with geo-referenced databases, can be used to analyse the impact of proposed measures, e.g., by simulating the flow and water level variations in the river and on flood plains during floods. Models can also be used to screen alternative management options and policies, monitoring and assessment strategies, optimize network design, and determine the potential impacts on water bodies and the risks to human health and ecosystems. Moreover, models play an important role in flood forecasting and early-warning systems (flood forecasting, travel time calculations in emergency warning systems in the event of accidental pollution in accidents and spillages).

Models should be carefully calibrated and validated with historical data to avoid unreliable results and misunderstandings of the behaviour of the basin or aquifer. Successful mathematical modelling is only possible if the approach is properly harmonized with data collection, data processing and other techniques for evaluation of the characteristics of the whole transboundary water system. It is essential that the model system applied is transparent and, if possible, based on open-source software. Also, the model structure and parameter choices have to be understood and presented to the joint bodies. Preferably several models (cloud modelling) should be used, and their results compared. The projections produced by different models should be opened and discussed in joint

meetings of experts. If both the conceptual model and the basic data for validation are agreed on and reliable, then the model comparison can be carried out using the same data if the modelling software used by the riparian states is not the same.

6.4. Using pilot projects

Pilot projects are important in establishing effective and efficient monitoring and assessment programmes. Furthermore, pilot projects help to initiate bilateral and multilateral cooperation, leading to institutional strengthening and capacity-building. As part of a step-by-step approach, it is desirable to implement pilot projects before setting up full monitoring and assessment systems for all the riparian countries' transboundary waters. The advantage of such an approach is that organizations with a direct or indirect stake in the use and management of transboundary waters can be involved in pilot projects. Most important, a road map is an inherent part of pilot projects, as the projects have achievable objectives and clear and realistic tasks which take into account the specific characteristics of the basin, lake or aquifer. These characteristics include the number of riparian countries and their proportions in the basin; the political, social, institutional and economic situation of the countries; and the nature of the basin. However, the commitment, resources and time needed should not be underestimated.

7. Implementing monitoring programmes

7.1. Monitoring and assessment cycle

Monitoring and assessment of watercourses, including transboundary waters, follow a certain sequence of activities, which is reflected in Figure 4.



Figure 4: Monitoring and assessment cycle

The outputs produced by each of these elements are used in the consecutive element(s) of the cycle. Ideally, at the end of the cycle, the information needed for planning, decision-making and operational water management at local, national and/or transboundary levels is obtained in the form of a report or other agreed-on format. It should also become clear what kind of information is still needed for better decision-making and other water management tasks, given that policies and/or targets may have changed in the meantime. Thus, a new cycle would start, leading to redefined or fine-tuned information needs, an “upgraded” information strategy, and so on.

7.2. Information needs

The analysis of water management issues is the basis for specifying the information needs. Information needs are related to:

- Uses (e.g., drinking water, irrigation, recreation) and functions (maintenance of ecosystems, protection of habitats and aquatic species) of the watercourse that put requirements on its quality and availability;
- Issues (e.g., flooding, sedimentation, salinization, pollution, morphological alterations and damming) that hinder proper use and functioning of the watercourse; and
- Measures taken to address the issues or improve the use or functioning of the watercourse, including environmental aspects and protection of biodiversity.

The information needs should be clearly determined for different levels (e.g., basin-scale and local levels), and using the components of the DPSIR framework.

To identify issues and priorities related to the use and protection of a transboundary river, lake, groundwater or transitional water, and their ecosystems, several activities are needed. These include identification of the functions and uses of the basin, inventories on the basis of available (and accessible) information, surveys (if information is lacking), identification of criteria and targets,

and evaluation of the water and environmental legislation in the riparian countries to identify provisions that are important for monitoring and assessment (Figure 5).



Figure 5: Analysis of water management issues

To specify information needs, information users and producers should interact closely. The institutions responsible for the protection and use of the transboundary watercourses, especially joint bodies, should be involved in the process of identifying and specifying information needs. Information needs have to be specified to such an extent that proper design criteria for the monitoring and assessment system can be derived. The information needs should be based on identified management issues and the decision-making process in basin management⁵⁵. Especially in defining information needs, close consideration of gender issues is needed.

Inventories of available information should bring together information that may, while available, be incoherent and distributed among different agencies/institutions. This includes not only the listing of information available from historical data, licenses and the like in administrative databases, but also a general screening and interpretation of all information relevant to the aspects under consideration.

Inventories should cover the major aspects that are relevant to the identification of the issues. These include, for example, water uses and water needs in the basin; run-off characteristics and the probability of flood waves and ice drifts; morphological alterations of lakes and rivers; declines in groundwater levels; droughts; water quality; state of the ecosystems as well as protected areas and aquatic species; decline in fish stocks; and sources of pollution from industries and municipal waste (especially the “hot spots”). The latter should be characterized in terms of, for example, production process, pollution composition and discharge load, land uses, and diffuse pollution sources with a register on the use of fertilizers and pesticides in agriculture. Other sources of pollution may include traffic and airborne pollution (which sometimes cause acid deposition), potential sources of accidental pollution such as pipelines, and other existing point pollution sources (e.g., uncontrolled waste disposal sites). The sources may also include ore and salt deposits, which are responsible for a certain “background” due to geophysical and geochemical processes.

⁵⁵ The paper ‘The Information Strategy Model: a framework for developing a monitoring strategy for national policy making and SDG6 reporting’, available at <https://www.tandfonline.com/doi/full/10.1080/02508060.2021.1973856>, describes a methodology for specifying information needs.

Surveys will be needed if the inventory does not provide sufficient data. Water-quality surveys are intended to give a first insight into the structure and functioning of the aquatic ecosystem and the occurrence of pollution and toxic effects in the water. Investigating the qualitative and quantitative structure of the biocoenose⁵⁶ concerned makes it possible to assess the ecological status of a river, lake or transitional water. Chemical screening of surface water, groundwater, sediments and effluents at hot spots and key locations can be performed. Additionally, specific target compounds that might be expected according to the inventory can be analysed. Toxic effects in surface water, sediments and effluents can be investigated at these locations. Surveys of water uses may also be required.

Water balances⁵⁷ or water accounts⁵⁸ should be drawn up for (parts of) a basin (especially lakes and aquifers), when and where the careful sharing of available water resources for different water uses is of special importance. Water management balances compare water resources with water uses, consumption and ecological water demand. In addition to undisturbed river run-off, a water management balance includes, for instance, intakes from and discharges to the river by municipalities, industries, irrigation, and drainage and fish farming; diversions from and into the river; reservoir storage and release; discharge of groundwater resources into the river, mine dewatering, etc.

Healthy ecosystems are essential for resilience and sustainable development, providing essential products and benefits. Water quality and quantity are of importance for ecosystems and should be included in the information needs⁵⁹. This includes not only aquatic ecosystems, where a flow regime (e.g., ecological flow) is to be maintained but also ecosystems that are dependent on groundwater, where certain groundwater levels may be critical for maintaining the ecosystem health.

Information needs should be further specified to be able to design a monitoring and assessment programme. The specified information needs should at least lead to:

- Appropriate variables to be monitored;
- Criteria for assessment (e.g., indicators, early warning criteria for floods, droughts or accidental pollution);
- Protected areas and other vulnerable and valuable environments that need to be considered;
- Specified requirements for reporting and presenting information (e.g., presentation in maps, GIS, degree of aggregation);
- Relevant accuracy for each monitoring variable;
- Degree of data reliability;
- Specified response time (i.e. the period of time within which the information is needed), for example, for forecasts or early warning systems (e.g., minutes/ hours), for trend detection (e.g., number of weeks/months/years after sampling) and other tasks.

⁵⁶ A biocenosis describes the interacting organisms living together in a habitat.

⁵⁷ A water balance is used to describe the flow of water in and out of a system. The water balance tracks water input and output as well as the different forms it can take as liquid, solid (snow and ice), and gas (evaporation).

⁵⁸ Water accounting is defined as the systematic acquisition, analysis and communication of information relating to stocks, flows, and fluxes of water (from source to sinks) in natural, disturbed or heavily engineered environments (<https://www.wateraccounting.org>).

⁵⁹ Also see the training manual '[Integrating data to improve the protection and restoration of freshwater ecosystems](#)'

The relevant accuracy and the degree of data reliability are decisive factors in the selection of monitoring sites, the determination of monitoring frequencies and the choice of laboratory technology and methodologies for data management.

Information needs should be prioritized. Information is mostly needed on high-priority issues. If the same information need arises from a variety of water management problems, this information need should be given high priority, because collecting this information once makes it possible to address a variety of issues.

7.3. Information strategy

After information needs have been identified, specified and prioritized, an information strategy should be developed. This defines the best practical way of gathering data from various sources including the monitoring system, expert judgments, statistical publications, open data sources, remote sensing, citizen science, indigenous and local knowledge, and the document libraries of various institutions (see Section 7.4). The information strategy should culminate in a monitoring plan and a plan for gathering data from a range of sources.

The information strategy needs to be adapted over time, as water management develops, targets are attained, or policies have changed. However, it should be recognized that there is a need for continuity to produce time series that make it possible to detect significant and reliable trends. Environmental monitoring programmes should always be seen as requiring long-term commitment.

7.4. Monitoring/data collection

The main monitoring objectives for rivers, lakes and groundwaters as well as effluents are to generate information, to be used both in national and transboundary contexts, for:

- Assessing the actual status of water resources;
- Detecting possible long-term trends in water levels and discharge or pollutant concentrations;
- Providing for hydrological forecasts;
- Assessing pollution loads from point and non-point sources;
- Testing for compliance with permits for water withdrawal or discharges of wastewater and establishing taxes, fines and sanctions;
- Verifying the effectiveness of policy measures;
- Contributing to reporting on the state of the environment;
- Providing early warning to protect the intended water uses in the event of flooding, drought or accidental pollution;
- Recognizing and understanding processes in water and water-related ecosystems (e.g., flow regime, erosion patterns, morphological alterations and damming, hydrobiological processes, natural or background pollution of water bodies);
- Enabling assessment of imminent or possible health risks and supporting predictions of long-term processes, which may have health-relevant outcomes; and
- Revising, if appropriate, the existing monitoring and assessment activities, including the existing monitoring system.

Each of these objectives may require specific measurement devices or sampling procedures.

The most resource- and labour-intensive phase in monitoring is the one that includes sampling, in situ physico-chemical analysis, hydrobiological and water-quantity-related measurements, and

laboratory analysis. This phase also entails high risks in producing reliable and accurate data. To support such analyses and to facilitate consistency across borders, it is essential that the data be compatible, comparable and of known quality⁶⁰. Therefore, it is important to employ qualified and experienced personnel and comply with internationally agreed guidelines and standards. Standards are necessary to secure the compatibility, comparability, interoperability and quality of data and information. A standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose, preferably based on an internationally agreed standard (e.g., International Organization for Standardization (ISO) standard). The aims and benefits of standards are:

- Improve quality and trust
- Enable exchange of data
- Increase comparability of measurements
- Improve understanding of uncertainty

The process thus becomes outcome and information oriented. Moreover, standards are highly important in the transboundary context. Characteristics of standards are:

- performance focused
- precise
- complete
- unambiguous,
- state of the art
- comprehensible to qualified person not having participated in their development

In this respect, in a transboundary setting it is important that a standard setting organization is appointed to oversee the process and that there are procedures to support this task⁶¹. Next to standards, laboratory proficiency testing and intercalibration exercises⁶² are needed to ensure comparability.

Additional data collection is needed to be able to make an integrated assessment of the boundary conditions and the broader social and environmental context. This includes human activities that may influence the state of the water resource and the ecosystem as well as policies and plans.

7.5. Different data sources

The integrated assessment requires data collection from a range of sources including expert judgments, statistical publications, open data sources, policies and plans next to monitoring data. Different organisations can provide different types of data and information and cooperation is therefore needed.

In addition to the more traditional monitoring through in-situ visits and sampling, technological developments allow for monitoring that may reduce the workload and resources needed or increase the amount or detail of information. Some technologies have not matured entirely and for some,

⁶⁰ Also see the report 'UNECE Task Force on Monitoring and Assessment: Quality Assurance', available at https://unece.org/DAM/env/water/publications/documents/quality_assurance.pdf

⁶¹ The Manual on the WMO Information System sets out standard and recommended practices and procedures, available at https://library.wmo.int/index.php?lvl=notice_display&id=9254#.YgPMly-iFaR

⁶² See, e.g., ISO/IEC 17025:2017 General requirements for the competence of testing and calibration laboratories (<https://www.iso.org/standard/66912.html>)

good examples exist. Below is a non-exhaustive list of developments. Depending on the specific basin and monitoring needs, specific technologies can be selected. For groundwater, e.g., remote sensing may not be applicable.

7.5.1. Remote sensing and Geographical Information Systems (GIS)

Remote sensing (RS), and especially satellite imaging has developed substantially⁶³. Advantages of RS are the large area that can be covered and the fact that it does not require in-situ visits except for ground truthing purposes. Disadvantages include the fact that clouds may hinder satellite imaging, the level of detail (resolution) is relatively low, imaging is mostly limited to the water surface and the temporal coverage may be limited. Also, applications for, for instance, water quality are limited.

Combined with GIS, satellite images can be used to provide good information on, among others, land use, vegetation and soil moisture. Models in combination with GIS provide good opportunities to identify hot spots and show geographical relationships. Also, much open access data are available for GIS and GIS can be a good basis for sharing and exchanging data.

7.5.2. Emission registration

Emission registration by companies (self-monitoring) provides a good source of information, particularly for water quality purposes. This entails obliging companies to report on their emissions, discharges and losses to air, water and soil. Such an obligation can be part of the operating license. Regular checking that the reports are reflecting the actual emissions, usually done through inspections, is necessary.

Such a registration system covers the point source pollution. For diffuse pollution, various methods exist that enable calculating pollution loads from various sources, including agriculture and road and rail transport. With this information, estimates can be made of the various sources of pollution. This in turn provides information on where measures can be effective.

7.5.3. Citizen science

Citizen science⁶⁴ is a process by which everyday people actively contribute to research and monitoring. There is a long tradition in hydrological monitoring to use local people to make the observations and feed the data into the official hydrological data bases. Regarding water quality, citizens can be provided with rather simple testing kits with which they can monitor water quality. Mobile phones have significantly simplified and accelerated the reporting phase in this type of monitoring. However, application of citizen science in monitoring requires long term commitment by citizens as well as their sufficient training by professionals to ensure quality and credibility of data. Gender aspects are relevant when developing citizen science platforms, set of observations to be collected and information flows, in order to ensure equal opportunities for reporting, access, and reachability of the information gathered.

7.5.4. Drones

Drones are vehicles that can be operated from a distance. A floating drone can, for instance, be programmed to make transects in a lake and take a sample or measurements at regular intervals.

⁶³ See, e.g., “World Bank. 2019. New Avenues for Remote Sensing Applications for Water Management: A Range of Applications and the Lessons Learned from Implementation” available at <https://openknowledge.worldbank.org/handle/10986/32105>

⁶⁴ See, e.g., <https://citizenscience.org>

This is in general cheaper and often more precise than a boat with some people that do the sampling. A submarine drone can take samples at different depths. These devices are largely still under development but are expected to develop quickly. Use of drones requires relevant permissions/licenses for operations. Moreover, specific attention should be paid to sharing and open access to data and videos in the joint basins.

7.5.5. Sensors

More and more, (automatic) sensors become available that can measure certain variables, replacing chemical analysis. This enables installing automated monitoring stations that collect data continuously or at regular intervals. Communication technology enables remote on-line collection of the data. Sensors can, e.g., also be installed on ferry boats to collect regular transects, or on drones. Note that sensors need regular maintenance and cleaning.

The amount of data collected using automated sensors is increasing exponentially. Therefore, the data transfer and quality control procedures of the large amounts of data need to be ensured and included in the cost of monitoring.

7.5.6. Environmental DNA

Environmental DNA (eDNA) is DNA from organisms that can be found in the aquatic environment and that can be sampled and monitored. Using eDNA may allow for rapid, cost-effective, and standardized collection of data about species distribution and relative abundance. These analyses are not largely used in operational monitoring and require specific protocols, instrumentation, and trained staff, in order to be used in environmental monitoring and assessment.

8. Managing and exchanging data and making assessments

8.1. Data management

It is of utmost importance that policy makers and planners better understand the various steps in data management. This facilitates data exchange among the institutions undertaking the monitoring and assessment, including joint bodies. It may be useful to start interinstitutional cooperation and data sharing at national level before bringing it to the transboundary level. To safeguard the future uses of the data that have been collected, the following steps are required before assessments can be made.

8.1.1. Developing a data dictionary

To facilitate the comparability of data, clear agreements should be made between the neighbouring countries on the definition, coding and formats of collected data and supporting information. The adoption of internationally standardized format for data exchange simplifies the technical implementation of the system and enables exchange at a wider scale. Collected data for a given instance include the date, location, measuring depth and measured values. Supporting information (metadata) includes information about characteristics of the location, the type of sample or sensor and the type of measurement or sampling installation, any preconditioning procedures and analytical techniques, including detection limits. A data dictionary explaining the coding and defining terms should be prepared and agreed on.

8.1.2. Data validation

Data validation is an intrinsic part of data management and includes regular checking and control of newly collected data (detection of outliers, missing values and other obvious mistakes). Computer programmes are available to perform various control functions, but expert judgment and local knowledge of the water systems are also indispensable for validation. When the data have been thoroughly checked and any necessary corrections or additions made, they can be approved and made accessible. Raw data can be made available for managing emergency situations, such as accidental spills of pollutants. However, such data need to be flagged and validated before entering regular data bases.

8.1.3. Data storage

To be available for future use, data should be stored in databases. The dimensions and units should always be included. Enough supporting information to enable interpretation, comparison, processing (conversions etc.), and reporting should also be stored. This supporting information is often referred to as metadata. The database should have safeguards against the entering of data without supporting metadata. The original raw data shall always be saved, separate from the corrected data.

Databases can either be national or shared between the riparian countries. In all cases, information availability for all riparian countries needs to be ensured.

8.1.4. Managing data from multiple sources

Management of data from multiple sources (monitoring datasets, maps, land-use characteristics, satellite imagery, socio-economic data) requires qualified and skilled ICT staff, computers and suitable software. Given that different concepts for databases may be used, at least compatible interfaces should be developed. As many countries have heritage data management systems with

incompatible, often proprietary, formats, the adoption of open standards for the exchange of water observation data facilitate the management of multiple sources, at national and international level

8.1.5. Data analysis and interpretation

The conversion of data into information involves analysis and interpretation. Data analysis should be embedded in a data analysis protocol (DAP) which clearly describes how the data should be analysed and interpreted and what should be done in case of missing data, outliers, non-normality and serial correlation.

The data analysis may be largely a statistical operation or set of operations using generic software packages. Statistical techniques may be used to detect trends and trend reversals and test for compliance with standards. The use of tailor-made adaptations to the software may be desirable. The DAP should therefore include procedures for processing the monitoring data to meet the specific interpretation needs (for example, calculations based on individual measurements or yearly averages, single sites or averages for the whole water body).

The DAP should be extended to reporting formats for the resulting information. Thus, the DAP should specify the format of the report, the frequency of publication, the intended audience, distribution procedures and the types of conclusions to be drawn and represented.

8.2. Assessment methodology

The assessment methodology will determine or at least influence the design of the monitoring programme. Therefore, it should be drawn up in parallel with undertaking an analysis of information needs and designing the monitoring programme, and should be focused on the legislative context, policies and issues.

Given the purposes of assessments, a simple way of using monitoring results is based on certain key variables and indicators. Especially in cases where binding water protection targets for certain pollutants, like pesticides, have been expressed by numerical norms or standards, comparing the state of the watercourses with them is a straightforward task and can be done in a very early phase. Another simple yet informative method of assessment is to prepare maps of the distribution of the monitored variables for certain larger water areas. Such an assessment is particularly appealing and understandable for laypeople. Where standards and norms differ between riparian countries, normative targets can be used to compare between the countries.

In monitoring programmes, where large amounts of different data are collected continuously over several years, statistical methods are needed to effectively summarize the results of monitoring. In particular, different types of trend calculations are being used to assess monitoring data. In interpreting trends in water quality, particular attention should be paid to water-quantity data, since hydrology strongly affects water quality. Flow normalization is regularly used, e.g., to assess and compare pollutant loads.

The use of water classification systems to assess watercourses is very common. Some of these systems are based on physico-chemical variables, but biological approaches (such as ecological classification under the WFD) are also used. For transboundary water assessments, whether based on classification systems or on other assessment methods, it is important to initially strive for comparability of results rather than unification of methods and standards as unification can be a very long process.

8.3. Data exchange

At transboundary level, the exchange of information and data between countries is often difficult for political/structural reasons (particularly when there is no agreement or protocol between the countries on data sharing), and technical reasons (difficulties related to information collection, harmonization of data formats, definitions, analysis methods, frequency of data collection, density of monitoring networks and data processing). National authorities may also be reluctant to provide neighbouring countries with information that they consider strategic, e.g., the economic value of water used for hydropower, agricultural irrigation and navigation may increase this reluctance.

For a smooth data exchange, both transboundary and national institutions have to solve several issues, such as:

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

Considering that data management is primarily a tool to support water policy, its organization at transboundary level will depend to a large extent on the type of existing joint bodies and on the level of cooperation defined in the provisions of the agreements between the countries. A joint body with an operative secretariat may have the possibility to allocate human and financial resources:

- To improve data exchange;
- To organize transboundary data processing and information dissemination;
- To support / complete the data production processes existing at national level;
- To develop and manage the information system, where not based on national systems.

However, when no secretariat with specific resources exists, it is then necessary to rely on the national organizations' resources to support these processes, or on external resources. If the data exchange has been initiated in a project, the issue of sustainability of the implemented processes must be considered.

In any case, reminding that most of the data used for transboundary water resources management is generally provided by the national organizations, the transboundary information system should ideally be built relying on the national information systems with (direct) access to the datasets made available by national partners. This implies to reinforce the national capacities in data management and to develop the capacities to exchange comparable data and interconnect the partner information systems (interoperability), using common language (concepts/referential dataset) and common procedures. Moreover, formats for the exchange of data should be defined and agreed by the users. The data dictionary should be the basis for defining such formats.

In some cases, e.g., if a large number of countries share the basin, the relevant joint body may consider the establishment of a common platform and common procedures to facilitate data storage and exchange. The WMO Unified Policy for the International Exchange of Earth System Data

⁶⁵ and the guidelines for data exchange developed by EUROWATERNET ⁶⁶ may be suitable for supporting such activities.

⁶⁵ <https://public.wmo.int/en/our-mandate/what-we-do/observations/Unified-WMO-Data-Policy-Resolution>

⁶⁶ <http://dd.eionet.eu.int/index.jsp>

9. Reporting and using information

9.1. Reporting

Reporting is another essential step in the monitoring and assessment cycle. Reporting has a key role in making decisions on water management and on further development of monitoring and assessment programmes. Information about water resources contributes also to environmental reporting and may inform planning relevant for water-using sectors. Reports should be prepared on a regular basis. The main issue is to present the interpreted data in an easily accessible and understandable way tailored to the audience being addressed. This is best done by providing the information from the monitoring in of the legislative context, policies and issues on which the information is collected.

The same information should be ready to be used for various purposes, like different reporting obligations, and for various users. Any environmental information system should therefore be ready to serve a range of different purposes and not be designed for one purpose only.⁶⁷

9.1.1. Reporting obligations

Environmental information should be public, according to the principle 10 of the Rio Declaration, the Aarhus Convention and the Escazú Agreement. This has an especially important role in increasing public awareness of water problems and public participation in water management.

An inventory should be made of national and international reporting obligations to be able to cost-effectively fulfil reporting requirements laid down in national water management legislation, applicable transboundary agreements as well as relevant decisions taken in international forums. For transboundary river, lake and aquifer basins, reporting under the Water Convention and on the SDG indicator 6.5.2 is of special relevance.

9.1.2. Reporting formats and audiences

The level of detail included in the reports and the frequency of compilation also depend on the target audience. The content of the report should be targeted to the needs of an audience that includes international bodies, management and scientific institutions, national administrations and the public. Depending on the needs of the target group, the report contains aggregated information (e.g., indicators) and/or detailed information in tables, statistically processed data, graphs and geographically presented information.

Public authorities, including joint bodies, usually request information in a specific format and frequency, which are defined in reporting protocols or reporting schemes. Such reports are usually presented in writing to ensure unambiguous understanding of the results. In addition, public authorities may have ad hoc requests for information which are not predefined in reporting protocols but are related to specific current topics in water management. This kind of reporting has

⁶⁷ The EU-wide Shared Environmental Information System (SEIS) for an integrated collection, exchange and use of environmental data and information across Europe builds on the principles that information should be:

1. Managed as close as possible to its source.
2. Collected once and shared with others for many purposes.
3. Readily available to easily fulfil reporting obligations.
4. Easily accessible to all users.
5. Accessible to enable comparisons at the appropriate geographical scale and the participation of citizens.
6. Fully available to the general public and at national level in the relevant national language(s).
7. Supported through common, free, open software standards.

to meet strict requirements concerning response time and flexibility. Reporting or information on water resources may also be needed related to the environment, health or economic development involving water-using sectors.

Reporting to the public can be done by developing shortened versions of the regular reports in easy to understand language. Guidance is, among others, provided in the Aarhus Convention or Escazú Agreement. Specific attention should be paid to the accessibility of the information, particularly the accessibility of children, youth, elderly people, women, indigenous people, and minorities with deficiencies of accessing such reports should be considered.

A state-of-the-environment report should provide concise information for decision-making in water management. These reports typically provide information on the state and functions of the water body, describe the existing problems and the pressure they put on the water body, and give insight into the impacts of corrective measures. Their decision-making value is strongly increased by using visualization tools and indicators, in particular if the elements of the DPSIR framework are reported.

The form of a joint report for the purposes of water management in transboundary basins should be agreed upon in detail by the riparian countries. Harmonization of reporting is strongly encouraged. Joint reporting naturally requires a high level of data comparability. The reports should highlight the links between policy measures and the status of the water body of concern. Periodic assessments under the Water Convention, covering all transboundary water basins, are also recommended to encourage the evaluation of progress made under the Convention, stimulate the commitment of the members involved, and make results available to the public.

The Internet provides a powerful tool for sharing and communicating information and can be used to inform and involve the public. Updated recommendations on the more effective use of electronic information tools⁶⁸ under the Aarhus Convention provide useful guidance in this respect. Some authorities have been cautious in presenting environmental information and data to the public because of the risk of misinterpretation of information by laypeople. However, involving non-governmental organizations and the public in transboundary water management promotes awareness and stimulates more sustainable cooperation between countries.

9.2. Information use

The information produced must be used and should contribute to management decisions. Therefore, the information products in their various forms need to be made relevant, accessible and attractive to users. These products should convey the messages that the information users really need.

The information product should be based on the information needs as specified. In particular, the information should be clearly linked to the relevant components of the DPSIR framework. While much of the information derived from a monitoring programme has its most direct link to the status of transboundary waters, interpretation and assessment in relation to the drivers and pressures and how these are changing over time, and in relation to impacts on (for example) the health of water users, must be included. Information products specifically related to responses – for example, the effectiveness of measures to protect or restore – are required by water managers. The information product should consequently address the full range of the DPSIR framework, thereby enabling decision-making about future actions and measures.

⁶⁸ <https://unece.org/environment/documents/2022/02/updated-recommendations-more-effective-use-electronic-information>

Given the monitoring and assessment cycle, the use of the information should also feed back into the design of monitoring and assessment. This may lead to revision and improvement of the monitoring programme, as well as to the review of and possibly changes in the information needs and the consequent priorities for monitoring and assessment, including reviewing the most effective use of the available funding and ensuring inclusiveness of all relevant stakeholders in the information cycle. While the monitoring and assessment programme needs stability and continuity to meet information needs, the specific activities that make up the monitoring and assessment cycle should be flexible enough to suit changing drivers and pressures, new legal requirements and obligations, new information needs of the society, and otherwise changing conditions. The monitoring and assessment cycle should, therefore, be seen as an inclusive, continuously evolving, and gradually improving spiral.

Annex 1. Specific aspects of groundwater monitoring

This annex represents an updated synthesis of the information from the Guidelines on Monitoring and Assessment of Transboundary Groundwater ⁶⁹.

Characteristics

Groundwater distinguishes from surface water in the slow movement (long residence times) of groundwaters. This increases the potential for their quality to be modified by the interaction between the water and the surrounding aquifer material. The interaction between aquifer material and water causes the natural hydro-geochemistry to evolve as the infiltrating groundwater moves down. Next to this, once groundwaters are polluted as a result of human activity, they may remain so for many years, and it is difficult to intervene effectively in this process.

Groundwater can be replenished by precipitation or from surfacewater bodies, but some aquifers have little or no interaction with the surface and the water is not renewable. Also, especially in heterogeneous hydrogeological settings, groundwater can have a high spatial variability.

Groundwater flow can be intergranular and/or through fractures. Groundwater flow will be much more rapid but variable and difficult to estimate through intensely fractured or karstic rocks.

Important variables

The characterisation and description of the transboundary aquifer system or a conceptual understanding of the groundwater body is a prerequisite for the monitoring and assessment of transboundary groundwaters. To be able to detect and quantify the superimposed impacts of human activities, the "baseline" quality and quantity of groundwater with its spatial (including depth) and time variations must be assessed. For instance, groundwater in superficial aquifers and essentially non-renewable groundwater resources can differ greatly in their characteristics.

Recharge and discharge areas need to be determined and activities that might affect the quantity or quality of groundwater need to be understood. Moreover, the interaction between surface and groundwaters as well as between groundwaters need to be understood. So, to characterise groundwater bodies, information on geology, geophysics and hydrogeology in the transboundary area, and aquifer system in particular, is important. The dynamics of the groundwater flow system, such as seasonal or longer-term responses and variations and changes in flow rate or direction caused by human activities, particularly groundwater abstraction, is important information.

Frequencies

The monitoring of groundwater quantity is different from the monitoring of groundwater quality. Groundwater quantity monitoring is usually done through a monitoring network, where the same wells are monitored at frequent intervals. Groundwater quantity monitoring is often done through surveys. As groundwater flow is generally slow, frequency of monitoring must be adjusted to the groundwater flow system.

Groundwater quality and quantity is variable in space and time, but on different spatial and temporal scales to surface waters, and this variability is made more complex by the interactions referred to above and with the geological media. The choice of the type and location of observation points and observation depths is usually governed by the specific representativeness of the

⁶⁹ <https://unece.org/DAM/env/water/publications/assessment/guidelinesgroundwater.pdf>

observation points in the aquifer and the possibility of determining the spatial trend in the groundwater levels or hydraulic head pressures on the required scale.

Locations

Aquifers are three-dimensional, sometimes complex environments. Monitoring data must therefore be taken in different places and at different depths.

Monitoring sites for groundwater level observation can be wells, springs or boreholes. Monitoring targeting potential impacts or abstraction may be purposely positioned in such areas. The sites or observation points of a network should be representative of the delineation of the relevant groundwater flow systems and the extent of aquifers, aquitards and aquicludes or the delineation of geohydrological units, among others. Accessibility of monitoring locations can be a limiting factor.

Knowledge of the groundwater flow system involves in particular the locations of groundwater recharge and discharge zones, and the way groundwater flows through aquifers from zone to zone (Figure 6). Activities in the recharge areas on one side of the border might adversely affect the quality of quantity of groundwater on the other side (Figure 7). When there is more than one aquifer separated by (horizontal or vertical) aquitards⁷⁰, the possible pathways or connections between them need to be understood.

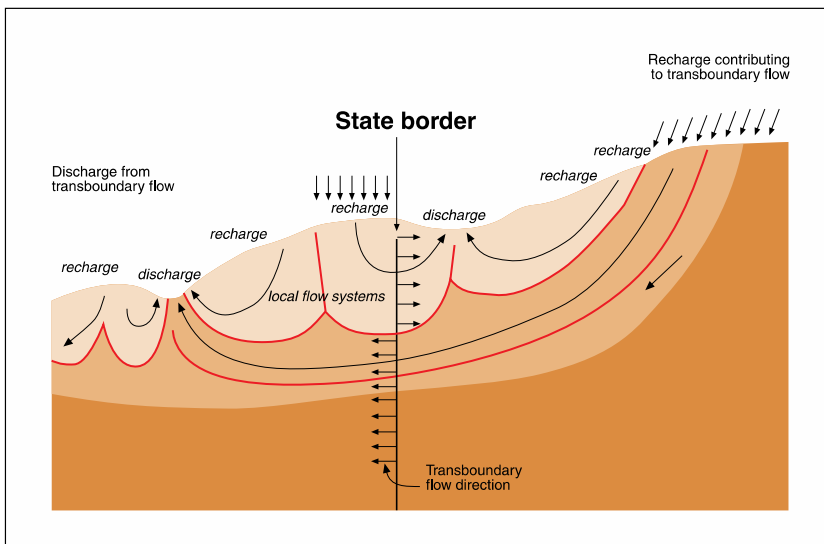


Figure 6: Transboundary groundwater flow systems (source: groundwater guidelines)

⁷⁰ Aquitard is a formation with a relative low permeability with respect to surrounding formations.

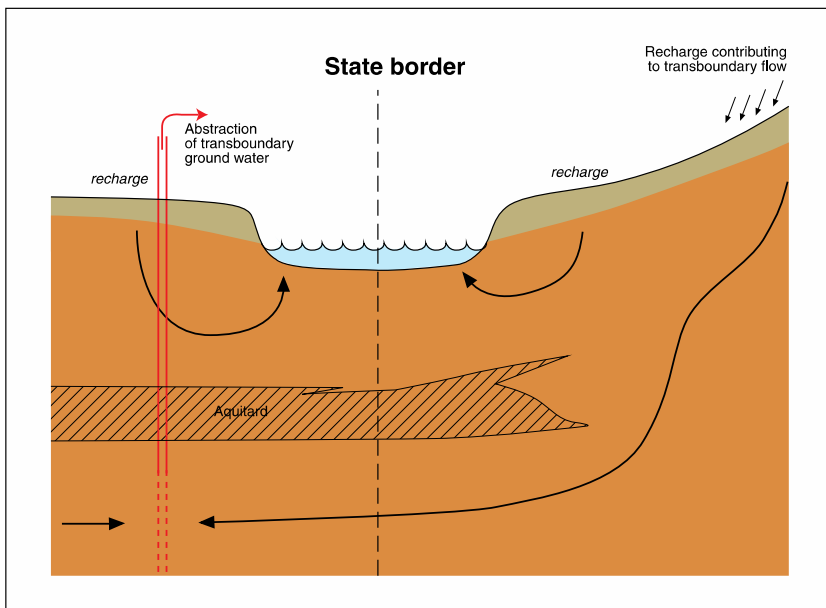


Figure 7: Effect of a transboundary aquitard on groundwater flow (source: groundwater guidelines)

The desirable or target density of a network is basically determined by the hydrogeological and the hydro-chemical complexity of the aquifer as well as the purpose of the monitoring. Hydrogeological units with a high degree of heterogeneity will require a denser network of monitoring sites. In aquifers affected by intensive exploitation and/or other anthropogenic impacts (industry, intensive agriculture, landfills, abandoned municipal or industrial sites, etc.), the network density should be higher. As a general rule, weighting factors as aquifer characteristics, vulnerability, groundwater exploitation, water use and land use, and population served with groundwater can be used as a reference in network design.

Annex 2. Specific aspects of lake monitoring

This annex represents an updated synthesis of the information from the Guidelines on Monitoring and Assessment of Transboundary and International Lakes ⁷¹.

Characteristics

Lakes differ from rivers as ecosystems in many respects, such as their hydrological circumstances, thermal properties, production/decomposition relations, sedimentation rates and composition, and the stability of certain phenomena. Lakes are almost closed systems. Substances introduced into a lake may become permanently incorporated into its cyclical processes, with only a proportion of the total load being removed, according to the rate of replenishment and sedimentation. Rivers are more open systems, where substances are more or less constantly transported downstream.

To carry out a reliable monitoring programme, the interactions between lakes and other water bodies should be clearly understood. Accurate long-term monitoring of the entire hydrological cycle is essential. Reliable assessments of ecological or chemical trends in any water body cannot be conducted without hydrological data. Most crucially, the factors controlling the water balance of a lake should be either measured directly or calculated by means of regional assessment or the water balance equation.

In many rapidly flowing stretches of rivers, water quality is quite homogenous, and wastes discharged into rivers may be diluted very quickly by the natural river water. But in lakes, waste-water can proceed through deeper waters during stratification periods for considerable distances without any real mixing. Heavier industrial waste-water effluents can destroy large areas of bottom sediments and their biota in this way. The concentrations of many pollutants may differ by factors of tens or even a hundred between the surface water level and bottom levels.

In some countries reservoirs are the most common type of water bodies. Artificial reservoirs can resemble natural lakes in many ways, but one crucial difference is that reservoirs are always built with a particular use in mind. The most common purposes for the construction of reservoirs are water supply, irrigation and hydropower generation. The main idea is usually to store water, delaying its flow from a wet period to a dry period, when the demand for water is higher. Where droughts can last many years, some reservoirs store up to three or four times the average annual flow. Exchange of information on the operation of reservoirs is important for transboundary cooperation.

The dominant biological process in rivers is the decomposition of organic matter, and primary production is much less important. In contrast, in deeper lakes with clear thermal stratification, the dominant biological phenomenon in the upper water layer during summertime is primary production. In the deeper layer, primary production cannot normally be detected, and the dominant process is the decomposition of organic matter by bacteria.

Sedimentation is also a very important process in lakes, and has a dominant role in nutrient cycles, and thus also in the eutrophication process. Sedimentation zones must be identified before monitoring programmes are implemented.

Important variables

From the point of view of the lake water balance, the key hydrological variables are typically regional precipitation, lake inflow, lake water level, lake evaporation, and lake outflow. Snow cover in

⁷¹ <https://unece.org/DAM/env/water/publications/assessment/lakesstrategydoc.pdf>

mountainous areas and groundwater storage are also important factors in many cases. Important physical hydrological phenomena such as sediment transport, erosion, water temperature and ice phenomena can also affect chemical and biological processes in lakes. Residence times also have a considerable effect on both eutrophication and the rate of recovery of polluted lakes.

The total volumes and residence times of the water in lakes vary greatly. Usually, the average depth of lakes is quite low, except in certain mountainous areas where maximum depths can reach several hundred metres.

Land use and other basin characteristics control the run-off process, so the management of a lake can greatly benefit from the use of geographical information systems (GIS). The morphological characteristics of the lake itself are of key importance. A bathymetric map – preferably in a data system format – can be used for the definition of the morphological features, as well as for various physical, chemical and biological studies.

The general status of the lake must also be considered. Major discharges must be monitored with a sampling network so that the effects of loading can also be estimated as a function of distance. The sampling of the critical ecosystem components that enable assessment of the healthy functioning of the lake ecosystem (such as phytoplankton, zooplankton, macrophytes, lake-bottom fauna, fish, invasive species, etc.) must be planned to support observations of physical and chemical characteristics as well as simultaneous hydrological observations.

Frequencies

A considerable part of the hydrological data should be collected in real-time or almost real-time to allow efficient lake management. Where data is collected to analyse basic hydrological variability, the requirement for real-time data is not relevant.

In lakes the vertical distribution of temperature depending on the season is an important phenomenon. During summertime, thermal stratification can be detected in all deeper lakes. In the upper water layer, the temperature is highest, and can be at the same level as the temperature in rivers at the same time. The temperatures in the deeper layer of the lake can remain much colder (5-10°C) during the entire stratification period. Therefore, in deeper lakes, seasonal vertical temperature distributions must be considered in sampling. Many lakes in higher latitudes are dimictic, i.e., the whole water mass only mixes twice a year, in spring and in autumn. Monitoring frequencies should account for such variation.

Locations

Different parts of a lake can have very different characteristics that need to be reflected in the selection of monitoring locations. A sampling network must be planned with the help of bathymetric maps and habitat maps, and suitable information on prevailing currents in the lake. The precise locations of waste-water outlets and other possible sources of pressure factors must also be known. Sampling sites are usually located in the deepest parts of lakes to allow the sampling of different layers of water. The number of sampling sites depends on the total area of the lake, and the possible existence of separate deeper waters. In addition to the sampling of deep waters, data from lake-bottom areas nearer the shoreline is also needed.

Annex 3. Specific aspects of river monitoring

This annex represents an updated synthesis of the information from the Guidelines on Monitoring and Assessment of Transboundary Rivers ⁷².

Characteristics

Rivers are part of the whole water cycle. To monitor rivers, their interaction with other waters should be understood. This refers to groundwaters and other surface waters (lakes and reservoirs) and the relation between fresh water and receiving coastal and marine waters.

River systems are considered to include their tidal estuaries with often dominating sedimentation problems (polluted sediments, dredging). Given the intense interaction between rivers and the seas into which they discharge, it is essential to harmonize the approaches to monitoring and assessment with those adopted under the existing sea treaties.

Important variables

A systematic analysis and assessment of water quality, flow regimes and water levels, habitats, biological communities, sources and fate of pollutants, as well as mass balance derivations, should be conducted in order to provide reliable information. Besides water level and river flow, water-quantity characteristics, e.g., sediment discharges, water temperature, evapotranspiration, ice and snow characteristics, are also important.

Flood-risk mapping is a useful management tool to indicate the areas that are most vulnerable to flooding in a geographical overview of the river basin. Geo-morphological information on flood plains is needed to estimate the flood frequency of connected areas. Hydrodynamic models can be used to estimate the flood situation in the river during extreme flood events. Model computations should also be used to estimate the impact of human activities on flood risks (such as river regulation works, flood protection works, water retention).

The morphology of rivers can be changing substantially with a varying discharge regime. River dunes are formed and subsequently washed away. River training ⁷³ measures are often taken to reduce the dynamics but especially in larger rivers, the variation can be huge. This may also influence the impacts of flood events. Information on the sediment dynamics may therefore be needed.

Low-flow conditions on rivers and drought over the catchment cause problems in water uses and the river's ecological functioning. In case of drought, more frequent information and data exchange on reservoir operation, diversions and water uses, as well as on hydrological and meteorological parameters might be necessary.

Flow management needs to be integrated in the overall river management. Application of the concept of environmental flows (e-flows) provide the means for integrated management of river flows to meet the needs of people, agriculture, industry, energy and ecosystems within the limits of available supply and under a changing climate. ⁷⁴

The assessment of ice conditions on rivers, lakes and reservoirs is of great interest in regions where ice formation affects navigation, interrupts the operation of river-regulating structures, or results in

⁷² https://unece.org/DAM/env/water/publications/assessment/guidelines_rivers_2000_english.pdf

⁷³ River training is performing engineering works like embankments, weirs or dredging to alter the hydrodynamics of the river in support of certain functions, like transport.

⁷⁴ See, e.g., https://www.iucn.org/downloads/water_briefing_eflows.pdf

damage to structures, and where ice jams may be formed (even to the extent of damming a major river). The obstruction of stream flow by ice can cause serious local flooding.

Frequencies

The continuous or frequent measurement of water levels and river flow is of the utmost importance for the management of a river basin. These basic characteristics play a role in all functions and uses of the river but are especially important for such aspects as water supply, navigation, ecological functions and protection against flooding.

The frequency of measurements, data transmission and forecasting depends on the variability of the hydrological characteristics and the response time requirements of the objective of monitoring. The seasonal distribution of flow in rivers depends heavily on their sources (e.g., the role of snow or glacier melt, presence of large lakes or base flow from groundwater; the beds of rivers flowing into desert sinks may be dry for a significant part of the year) but also on evapotranspiration.

Systematic water level recordings, supplemented by more frequent readings during floods, are needed for most streams. The installation of water level recorders is essential for streams whose level is subject to abrupt fluctuations. Continuous river flow records are necessary in the design of water-supply systems, and in estimating the sediment or chemical loads of streams, including pollutants.

Sampling should preferably be performed at or near to border crossings (e.g., to be able to show the contribution towards reduction targets per country). Sampling in the river and in the main tributaries upstream of the confluence is important to show the contribution (e.g., pollution load) of different tributaries. The selection of sampling sites downstream of a confluence should avoid the uncertainties related to incomplete mixing (mixing zones can be several kilometres long, depending on the width-depth ratio of the main river).

In general, locations in the main flow of the river will be chosen for water and suspended solid sampling. Bottom sediment can best be sampled in regions where the suspended material settles. As a consequence, most sediment samples are taken near riverbanks and in the downstream sedimentation area.

The number of sampling points for sediment monitoring strongly depends on the objectives. For trend detection, a low number of sampling points or mixing samples into composite samples can yield enough information. If spatial information is to be estimated, the number of sampling sites will increase, and no composite samples will be used.

Locations

It is necessary to have a clear picture of the part of the river of which a monitoring location and its monitoring results is representative. There are two levels at which a monitoring site can be representative:

- On a macro scale the selection of monitoring sites will be determined by the information objectives (far field representative);
- On a micro scale it is the local circumstances that determine the exact monitoring location (near field representative).

For the combined use of quantity and quality data (e.g., in case of calculation of loads), the location of hydrological measurements and of water-quality sampling should be the same as far as possible. Different locations are allowed only if the relationship between the hydrological characteristics of both sites is unambiguously known.

The selection of monitoring sites for the management of a transboundary river basin should be governed by the purpose for which the data or records are collected and by the accessibility of the site. For hydrometeorological parameters, spatial representativeness is crucial.

Major locations of gauging stations are the lower reaches of rivers, immediately upstream of the river mouth or where the rivers cross borders, near the confluence with tributaries and at major cities along the river (used for flood forecasting, water supply and transport). For flood risk, relatively high upstream locations or specific tributaries may be important in terms of significant and fast increase in contribution to the flow. In general, a sufficient number of gauging stations should be located along the main river to permit interpolation of water level and discharge between the stations. Water balances require enough observation stations at small streams and tributaries as well.

Annex 4. Specific aspects of monitoring in transitional waters

This annex is based on a few sources as listed in the footnote ⁷⁵ and on the Monitoring guidelines of the EU Water Framework directive⁷⁶ where there are specific recommendations for transitional waters.

Characteristics

Transitional waters are water bodies where the rivers meet the sea, i.e., estuaries, deltas, lagoons, and coastal brackish water lakes. Transitional waters and their surrounding wetlands are home to unique plant and animal communities that have adapted to brackish water. The mixture of seawater and fresh water in estuaries and in other transitional waters has a salinity in the range from 0.5 to 35 parts per thousand (ppt). The salinity of transitional waters can change from one day to the next depending on the coastal morphology, openness and exposure to the sea, tides, riverine flow, winds or other factors.

The tidal pattern depends on the geographic location, the shape of the coastline and ocean floor, the depth of the water, local winds, and any restrictions to water flow. Particularly, estuaries are strongly affected by coastal hydrodynamics (such as currents, mixing and upwellings), tides and tidal cycles, and the changing freshwater flow from the rivers. Many estuaries and particularly coastal lagoons are protected from the full force of ocean waves, winds, and storms by reefs, barrier islands, or fingers of land, mud, or sand that surround them.

Important variables

The hydrological budget characterizes the different transitional waters, as it determines the sediment distribution and affects the sensitivity and resilience of transitional water ecosystems. Consequently, the hydrological budget has a major influence on all variables in transitional waters.

Hydrological relevant parameters for an estuary are the volumes entering the estuary during high and low tide (tidal volume). The waterflow (volume and velocity) varies very locally. Subsequently erosion and sedimentation processes are sensitive to anthropogenic measures and extreme events like storm. It is fundamental to measure the salinity gradient horizontally as well as vertically.

Dissolved oxygen is critical for the survival of animals and plants that live in the water. The temperature of the water also indicates what types of plants and animals can live in the estuary.

Water levels in an estuary typically rise and fall with the daily tides, but they are also affected by periods of drought or excessive rainfall affect the amount of fresh water entering the estuary from rivers or runoff, and can easily change the physical, chemical and biological conditions in an estuary.

Estuarine organisms have different tolerances and responses to salinity changes. The salinity of the water is therefore also an important variable.

Turbidity indicates the sediments and other suspended solids in the water. Turbidity affects organisms that are directly dependent on light, like aquatic plants, because it limits their ability to carry out photosynthesis.

⁷⁵ https://oceanservice.noaa.gov/education/tutorial_estuaries/est01_what.html and https://19january2017snapshot.epa.gov/sites/production/files/2015-09/documents/2007_04_09_estuaries_monitoruments_manual.pdf

⁷⁶ Monitoring under the Water Framework Directive; CIS guidance document No.7. [https://circabc.europa.eu/sd/a/63f7715f-0f45-4955-b7cb-58ca305e42a8/Guidance%20No%207%20-%20Monitoring%20\(WG%202.7\).pdf](https://circabc.europa.eu/sd/a/63f7715f-0f45-4955-b7cb-58ca305e42a8/Guidance%20No%207%20-%20Monitoring%20(WG%202.7).pdf)

Finally, biological monitoring is important. Depending on the goals and objectives of the monitoring, appropriate biological group(s) should be monitored.

Frequencies

Environmental conditions change with the seasons, and monitoring results can reflect those variations. For example, nutrient and pesticide concentrations in estuaries vary considerably from season to season.

Locations

The monitoring locations are selected depending on the goals and objectives of the monitoring. Depending on the estuary, stratification may occur. Together with the tidal movements and possible issues that require monitoring information will determine what suitable locations are. Sampling depths is also relevant. Monitoring should be performed with data collection on all the freshwater inputs and outputs arranged on a seasonal scale.

Annex 5. International programmes and information sources

Environmental data and information are available through various on-line databases and websites. Monitoring and assessment activities under the auspices of United Nations organizations and programmes produce valuable information which can be used for carrying out assessments of transboundary water. Below is a selection of such programmes and information sources that is not intended to be comprehensive.

The GEMS/Water Programme ⁷⁷ is a major source of global surface- and groundwater quality data and provides information on the state and trends of regional and global water quality to support scientific assessments and decision-making. The Transboundary Waters Assessment Programme (GEF TWAP) ⁷⁸ contains information on biophysical parameters of waterbodies (including biodiversity, climate change, land degradation, waste, etc.), socio-economic information (including population, Human Development Index (as a proxy for consumption), etc.), and governance related parameters (including multi-lateral environmental arrangements, integrated national planning, etc.).

AQUASTAT ⁷⁹ is the FAO global information system on water resources and agricultural water management. It collects, analyses and provides free access to over 180 variables and indicators by country from 1960. Data and metadata are available on water resources (internal, transboundary, total), water uses (by sector, by source, wastewater), irrigation (location, area, typology, technology, crops), dams (location, height, capacity, surface area) and water-related institutions, policies and legislation. FAO has also developed WaPOR ⁸⁰, a publicly accessible near real time database using satellite data that will allow monitoring of agricultural water productivity. WaPOR uses satellite data to help countries monitor agricultural water productivity, identify water productivity gaps and find solutions.

Data and information on groundwaters can be obtained from the International Shared Aquifer Resources Management (ISARM) programme ⁸¹, which aims at developing methods and techniques for improving understanding of the management of shared groundwater systems, considering both technical and institutional aspects. The International Groundwater Resources Assessment Centre (IGRAC) ⁸², which facilitates and promotes worldwide exchange of groundwater knowledge to improve assessment, development and management of groundwater resources, is another important source of information. Its Global Groundwater Information System⁸³ is an interactive, web-based portal to groundwater-related information and knowledge.

The national hydrological/meteorological services of the member States of the World Meteorological Organization (WMO) operate over 475,000 hydrological stations worldwide. WMO's Associated Programme on Flood Management (APFM) ⁸⁴ aims to support countries in implementing Integrated Flood Management to maximize net benefits from floodplains and minimize loss of life from flooding. Its Integrated Drought Management Programme (IDMP) ⁸⁵ provides policy and management guidance through globally coordinated generation of scientific information and sharing of best practices and knowledge for integrated drought management. WMO's Global Runoff

⁷⁷ <http://www.gemswater.org>

⁷⁸ <http://www.geftwap.org>

⁷⁹ <http://www.fao.org/aquastat/en/>

⁸⁰ <https://wapor.apps.fao.org/home/WAPOR/1>

⁸¹ <https://isarm.org>

⁸² <https://www.un-igrac.org>

⁸³ <https://ggis.un-igrac.org>

⁸⁴ <https://www.floodmanagement.info>

⁸⁵ <https://www.droughtmanagement.info>

Data Centre (GRDC)⁸⁶ is a digital worldwide depository of discharge data and associated metadata and serves as a facilitator between data providers and data users.

Data on water-related disease can be accessed through the Health for All Database⁸⁷ of the World Health Organization (WHO). This database includes data on diarrhoeal diseases, viral hepatitis A and malaria incidence as well as on the number of people connected to water supply systems and having access to sewage systems, septic tanks or other hygienic sewage disposals. The WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) database⁸⁸ provides global data on water supply, sanitation and hygiene.

The SDG Global Database⁸⁹ provides data on more than 210 SDG indicators for countries across the globe. UN-Water supports countries in monitoring water- and sanitation-related indicators of the SDG 6.⁹⁰

Google Earth Engine⁹¹ provides a wide range of geophysical and weather and climate datasets.

At the regional level, one important source of information on the status of rivers, lakes and groundwaters in Europe is the European Environment Agency (EEA)⁹². Copernicus⁹³ is the European Union's Earth observation programme, offering information services that draw from satellite Earth Observation and in-situ (non-space) data. Copernicus provides services on the atmosphere, the marine environment, land-cover and land-use, climate change, border security and early warning. The Statistical Office of the European Communities (Eurostat)⁹⁴ collects statistics on water resources, water abstraction and use, and wastewater treatment and discharges.

In Asia, aiming to deal with climate change, the member states of the Association of Southeast Asian Nations have established the ASEAN Hydroinformatics Data Centre (AHC)⁹⁵ for Water and Disaster Risk Management.

The Regional Environmental Centre for Central Asia (CAREC) runs the Eurasian River Basin Portal⁹⁶ that provides support to water resources management and strengthening of the capacity of water management organizations in Europe and Central Asia as well as an information portal on climate adaptation and mitigation in Central Asia⁹⁷.

⁸⁶ https://www.bafg.de/GRDC/EN/Home/homepage_node.html

⁸⁷ <http://www.euro.who.int/hfad>

⁸⁸ <https://washdata.org/data>

⁸⁹ <https://unstats.un.org/sdgs/unsdg>

⁹⁰ <https://www.sdg6monitoring.org/> and <https://www.sdg6data.org/>

⁹¹ <https://earthengine.google.com/>

⁹² <https://www.eea.europa.eu/data-and-maps>

⁹³ <https://www.copernicus.eu/en>

⁹⁴ <https://ec.europa.eu/eurostat/web/environment/water>

⁹⁵ <http://www.aseanwater.net/wp/>

⁹⁶ <http://www.riverbp.net/eng/>

⁹⁷ <https://ca-climate.org/eng/>