Framework for Freshwater Ecosystem Management Series

Technical guide for classification and target-setting

Volume 2

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A Framework for Freshwater Ecosystem Management

Volume 2: Technical guide for classification and target-setting

Acknowledgements

The Framework for Freshwater Ecosystem Management series has been developed over several years and has involved more than 60 contributors: authors, reviewers and coordinators. This work was initiated by a decision by the United Nations Environment Programme's Governing Council in 2013 and a first progress report was provided at the United Nations Environment Assembly (UNEA) in 2014.

Volume 2 of the series draws heavily on Volume 4, 'Scientific background for regional consultations on developing water quality guidelines for ecosystems', which was prepared through a collaboration between UN Environment, United Nations University – Institute for Environment and Human Security, and the Global Water System Project. It was produced for the second UNEA in 2016 to inform the first interim draft documents of this series. Based on feedback from countries received during UNEA-2 and the ensuing regional consultation period, the original framework has evolved and been refined since the creation of the 'Scientific background'. Volume 2 was developed during 2017, at the same time as the baseline for the 2030 Agenda for Sustainable Development. The process of updating this work takes into account feedback from countries: that the work should align with Agenda 2030 and the Sustainable Development Goals (SDGs), and should be aimed towards assisting countries in setting up their own national standards, rather than prescribing a set of globally applicable water quality standards for ecosystems. For a more detailed description of the development process, see Annex 1 of Volume 1. For a full list of contributors to the series, see Annex 2 of Volume 1.

The Working Group for Volume 2 was led by the UN Environment–DHI Centre for Water and Environment (Paul Glennie, lead author, and Peter Koefoed Bjørnsen), with Neels Kleynans (lead author, formerly Department of Water Affairs, South Africa); under guidance from the Freshwater Unit of the Ecosystems Division at UN Environment (Joakim Harlin and Lis Mullin Bernhardt, with support from Emmanuel Ngore and Yeonju Jeong); with inputs from Deborah Chapman and Stuart Warner (University of Cork, Ireland, GEMS/Water), Birguy Lamizana (Global Programme of Action for the Protection of the Marine Environment from Land Based Activities / UN Environment), and Chris Dickens of the International Water Management Institute (IWMI).

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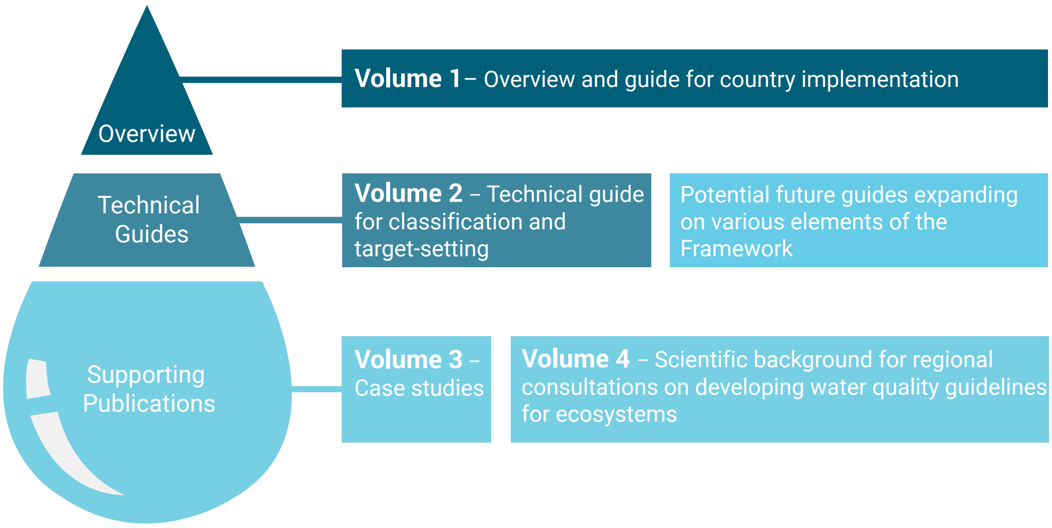
Preface: A Framework for Freshwater Ecosystem Management

The UN Environment Framework for Freshwater Ecosystem Management series presents a holistic management framework to guide country-level action to sustainably manage freshwater ecosystems. It builds on the decision by the UN Environment Programme (UNEP) Governing Council to develop water quality guidelines for ecosystems (Decision 27/3, 2013).

The Framework supports national and international goals related to freshwater ecosystems, such as relevant Aichi Biodiversity Targets and Sustainable Development Goal (SDG) targets. An overview of the series, which currently consists of four volumes, is provided below:

The Freshwater Ecosystem Management series



Volume 1 provides an overview of the Framework, and places it in the context of supporting Agenda 2030. It is intended for a wide audience, including decision makers, practitioners, scientists, non-governmental organizations and the general public.

Volume 2 describes aspects of the Framework in more technical detail: classification systems for freshwater ecosystem types, setting targets for ecological status, and monitoring progress against these targets. It is primarily aimed at government agency staff responsible for the sustainable management of freshwater ecosystems. These aspects have been selected for elaboration as they are likely to be the most useful for the largest number of countries in relation to Aichi Biodiversity Targets and the SDGs. Additional technical guides that expand on other parts of the Framework, such as the design and implementation of remediation actions, may be developed depending on demand from countries.

Volume 3 provides examples from around the world, illustrating different aspects of the Framework.

Volume 4 underpins the series and includes a review of water quality guidelines for ecosystems from around the world, which was produced for regional and country consultations early on in this process.

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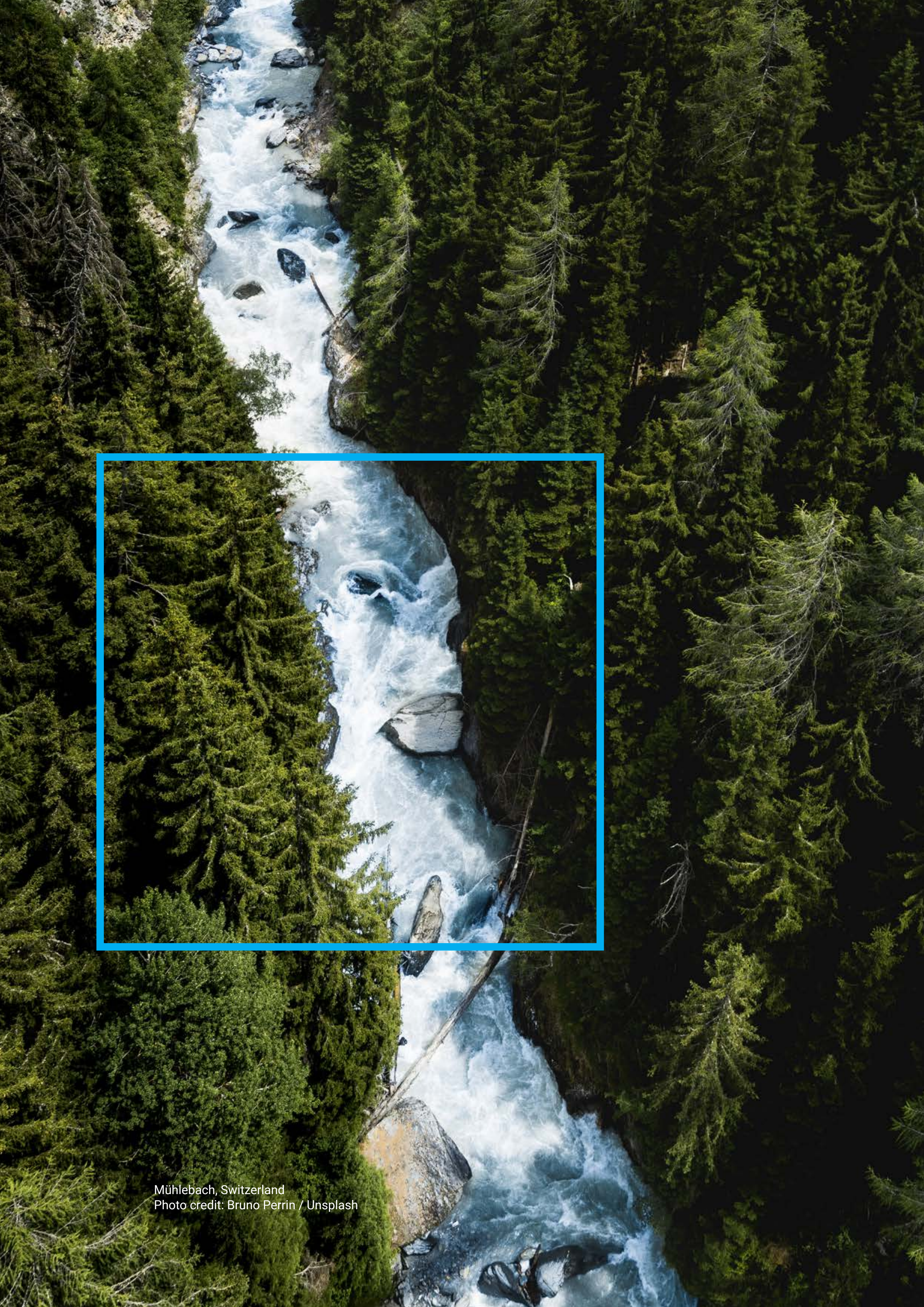


Mühlebach, Switzerland
Photo credit: Bruno Perrin / Unsplash

1 Introduction

Freshwater ecosystems such as wetlands, rivers, aquifers and lakes are indispensable for life on our planet and vital for directly ensuring a range of benefits and services fundamental to the environment, society and the economy (Box 1). These include water for drinking, agriculture, industry and energy production; critical habitats for fish, birds, mammals, reptiles, amphibians, insects and other invertebrates; and natural solutions for purposes such as water purification and mitigating the impacts of development and floods and droughts. With these services, and many others, freshwater ecosystems are essential for sustainable development, peace and security, and human well-being.

Context

This 'technical guide for classification and target-setting' is Volume 2 of the UN Environment Framework for Freshwater Ecosystem Management series. It expands on some of the steps outlined in Volume 1 'Overview and guide for country implementation'. An overview of the series is provided in the preface.

Aims

The overall aim of this volume is to provide countries with guidance on selected aspects of the Framework for Freshwater Ecosystem Management, particularly in the context of the Sustainable Development Goals (SDGs). The main objective is to initiate and contribute to national-level discussions to support implementation. It is not intended as a prescriptive manual. It outlines the main issues for consideration, provides examples, and notes links to relevant SDG targets and indicators. Each of the processes mentioned will require more detailed analysis and design at the national level. This volume is intended to support national processes and objectives, as well as working towards global political commitments such as those contained in the SDGs, which often stipulate that target values and indicator thresholds should be set at the country level. Consequently, this volume focuses on two aspects of the Framework: namely the design of classification frameworks for ecosystem types and services, and potential indicators; and the design of ecological status classes and indicator threshold values to distinguish between the classes (see Section 2 for further information).

For the purposes of this series, 'freshwater ecosystems' refers to all inland waterbodies. They include vegetated wetlands, rivers, streams, canals, lakes and reservoirs. They also include brackish water, such as estuaries, mangroves and lagoons. This is because the quantity and quality of freshwater inflows are often a critical factor in maintaining ecosystem functions in these water bodies. This is in line with the 'drainage basin' and 'source to sea' approaches to natural resources management. Finally, groundwater is also included because groundwater–surface water interactions are often a critical element in surface water ecosystem function; groundwater bodies also provide direct ecosystem services.

For the sake of brevity, 'freshwater ecosystems' are sometimes referred to in this volume simply as 'ecosystems'. For more information on ecosystem types see Section 3.1.

Box 1 - Freshwater Ecosystem Types

Target Audience

This volume is primarily developed for government agency staff responsible for sustainably managing, monitoring and reporting on freshwater ecosystems.
The processes (steps) outlined in this volume are intended to be broadly applicable to all countries, across regions and climates, and with varying levels of development and financial and technical capacity. However, the main target audience for this volume are countries with low to moderate levels of information on their freshwater ecosystems, wishing to initiate or develop existing systems to improve the knowledge base from which to make management decisions to protect and sustainably manage freshwater ecosystems. Throughout this volume, options and examples are provided within each step to cater for varying levels of country capacity.

Transboundary Freshwater Ecosystems and their Basins

The Framework for Freshwater Ecosystem Management is also intended for use at the transboundary level, where freshwater ecosystems and their basins are shared by two or more countries. There are at least 286 transboundary river basins, 204 transboundary lake basins, 199 transboundary aquifers and numerous transboundary wetlands.[1] While transboundary freshwater ecosystems are typically more challenging to manage than national ecosystems, the Framework offers a common platform for cooperation between countries, especially where transboundary institutions or cooperation frameworks are in relatively early stages of development.

Synergy with SDGs

While freshwater ecosystems provide a vast array of services to support sustainable development objectives and directly or indirectly support a large number of Sustainable Development Goals (SDGs) and their targets (see Table 1, Volume 1), the processes outlined in this volume are most closely linked with monitoring and reporting for the following SDG targets and indicators:

- Target 6.6: By 2020 protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.
    - Indicator 6.6.1: Change in the extent[2] of water-related ecosystems over time.

1 Note there is likely to be significant overlap between these water system types. See UNEP (2016), Transboundary Waters Systems – Status and trends: Crosscutting analysis. United Nations Environment Programme (UNEP), Nairobi.
2 'Extent' in SDG 6.6.1 includes spatial extent, water quantity, water quality and overall ecological health.

- Target 6.3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.
  - Indicator 6.3.1: Proportion of wastewater safely treated
  - Indicator 6.3.2: Proportion of bodies of water with good ambient water quality.

Note that SDG indicator 6.6.1 directly uses indicator 6.3.2 as one of its sub-indicators. Much more detailed information on these targets and indicators, including methodologies, is available at http://www.sdg6monitoring.org. This volume can be used in conjunction with the more detailed SDG indicator methodologies. It also supports the SDG indicator methodologies by providing the context in which they can be developed. Furthermore, it provides some information on the links between relevant SDG indicators, particularly SDG 6.6.1 and 6.3.2, thus supporting harmonization and streamlining of efforts related to reporting on those indicators. Throughout this volume, links to SDG targets and indicators are provided in green boxes. Note that the steps in this Framework do not have the same names or follow the same order as the steps described in the step-by-step methodologies for SDG indicators, though they are mutually reinforcing (see Annex 2 for a comparison).

While this volume is written within the time frame of the SDGs (2016–2030), and is intended to support countries reporting on indicators and working towards targets, the implementation and revision of this Framework is expected to continue beyond 2030.

Supporting the UN Environment Assembly

The Framework for Freshwater Ecosystem Management series has its origins in a request from the UN Environment Assembly (UNEA) to develop international water quality guidelines for ecosystems.[3] This volume contributes to the theme of the third UNEA (December 2017): 'Towards a Pollution-Free Planet'. It does this by outlining practical steps towards target setting and monitoring for freshwater ecosystems. These steps include an assessment of capacity, and the identification of capacity gaps that may need to be addressed. Monitoring freshwater is a critical element in the management cycle to reduce pollution.

3 UNEA formerly UNEP Governing Council. Decision 27/3, February 2013.

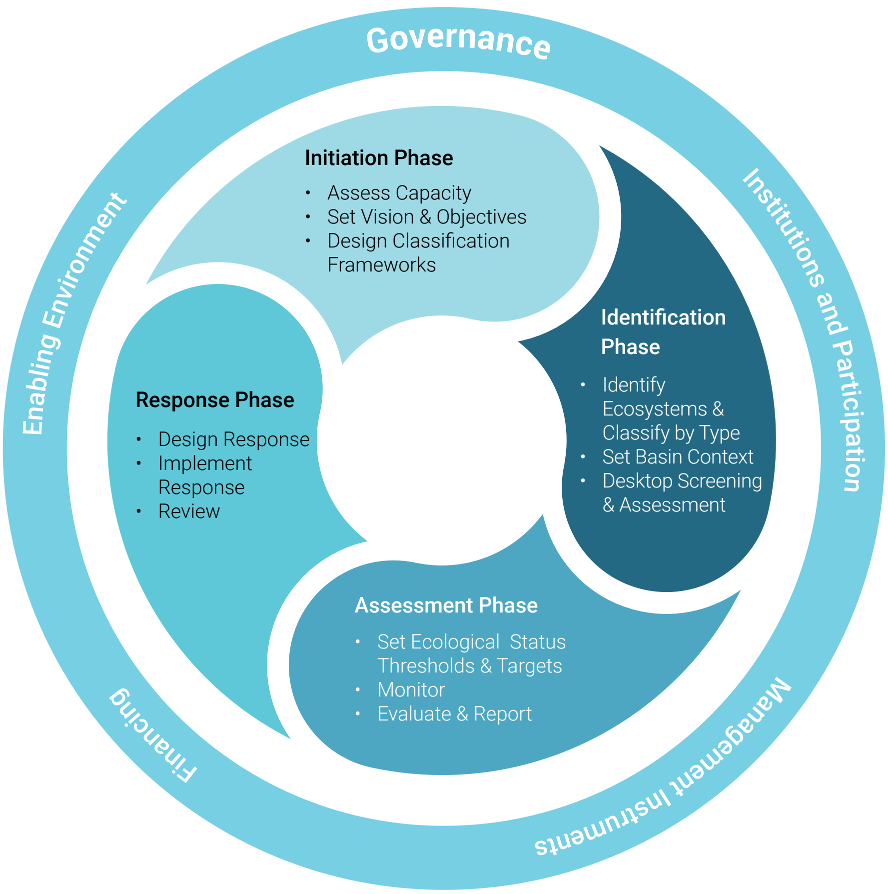
Gambia River, Gambia
Photo credit: Dan Roizer / Splash

2 The Framework for Freshwater Ecosystem Management

2.1 An Overview

An overview of the Framework for Freshwater Ecosystem Management is provided in Figure 1 and in the Framework Description Summary which follows. The steps are further broken down into sub-steps in Annex 1.

Figure 1 – The Framework for Freshwater Ecosystem Management, underpinned by good governance



4 More detail is provided on the steps and sub-steps in Annex 1.

While the phases and steps are presented in a logical order, they are not numbered as they do not have to be undertaken in sequential order. In most countries, work on many of the steps will happen concurrently, as different countries are expected to be at different levels of implementation in different parts of the Framework. Nonetheless, the Framework is generally designed to begin with capacity assessment in the Initiation Phase and to progress in a clockwise direction.

Good governance is essential for the sustainable management of freshwater ecosystems. Good governance is participatory, accountable, transparent, responsive, consensus-oriented, effective and efficient, equitable and inclusive, and follows rules of law. Governance underpins and effects all aspects of the four phases of the national Framework. Governance of freshwater ecosystems can be broken down into the following four components: (1) Enabling Environment; (2) Institutions and Participation; (3) Management Instruments; and (4) Financing (see Section 4 of Volume 1).

Framework Description Summary

INITIATION PHASE

Assess Capacity: Assess national capacities to sustainably manage freshwater ecosystems, including all aspects of governance (e.g. policies, plans, laws, institutions, monitoring programmes and financing).

Set Vision and Objectives: Agree on a broad national vision and objectives concerning freshwater ecosystems. Involve relevant stakeholders.

Design Classification Frameworks: Design classification system for ecosystem types (e.g. rivers, lakes, wetlands), define the potential ecosystem services for each ecosystem type, and identify potential indicators that could be used as proxies for the provision of ecosystem services.

IDENTIFICATION PHASE

This phase draws on existing data and information to identify, categorize and undertake a preliminary assessment of freshwater ecosystems.

Identify Ecosystems and Classify by Type: Using the classification frameworks designed in the Initiation Phase, identify and classify freshwater ecosystems, their services, and any key variables that are likely to influence the provision of ecosystem services.

Set Basin Context: Defining the hydrological drainage basin for each ecosystem facilitates an assessment of the main pressures on them, as well as the main recipients of the ecosystem services.

Desktop Screening and Assessment: involves gathering existing information at the basin level, identifying key pressures on each ecosystem, and making an initial assessment of ecological status of each ecosystem. The step should involve stakeholders and experts as appropriate to get the most accurate picture of the basin, without undertaking additional monitoring.

ASSESSMENT PHASE

Set Ecological Status Thresholds and Targets: involves the definition of ecological status classes (e.g. 'good' to 'bad'), the selection and design of indicators, specifying threshold values for each indicator, and assigning ecosystems to status classes. Finally, targets can be set, with involvement of stakeholders, for acceptable ecological status of each ecosystem.

Monitor: involves the design of the monitoring programme, the collection of data, quality assurance and data management.

Evaluate and report: involves analysing the monitored data, comparing them against the defined indicator thresholds, and assigning each ecosystem to an ecological status class.

RESPONSE PHASE

This phase concerns the management actions to sustainably manage freshwater ecosystems.

Design Response: Based on the assessment results (Phase 3), refine the objectives for each ecosystem, identify and prioritize management actions, and undertake detailed design of the selected management options. The aim is to attain the target status class.

Implement Response: implement the management actions designed in the previous Step. Review: review the effectiveness of the management actions, as well as review the entire Framework and identify steps that require revision.

2.2 Specific Framework Aspects Addressed in Volume 2

Expanding upon Volume 1 of the series, which provides an overview of the entire Framework, this volume expounds upon some of the more technical aspects of selected steps, which are expected to be of most use to a broad range of countries, in the context of implementing and reporting on particular SDG targets and indicators. Volume 4 contains further information, and scientific and technical detail on all aspects addressed in this volume.

This volume is structured in two parts – A and B. Part A forms the core of this volume and provides technical guidance on the following steps:

- Designing classification frameworks for ecosystem types (Initiation Phase) – Section 3
- Designing ecological status classes and indicator threshold values to distinguish between each class (Assessment Phase) – Section 4

Being able to identify different types of ecosystems greatly assists in the selection of indicators, and the design of guideline or threshold indicator values that can be used to determine the general health of a freshwater ecosystem, particularly in relation to water quality.

Part B of this volume provides more general guidance on other steps; namely capacity assessment (Section 5), identification and desktop screening (Section 6), and monitoring (Section 7). An understanding of the level of capacity in the country helps to set the potential scope for many of the steps in the Framework. This is linked to desktop screening for pressures and ecological status, which can be undertaken at a number of levels or resolutions, based on available data and level of capacity. While monitoring for particular SDG indicators is covered in more detail in the respective SDG indicator methodologies, Section 7 of this volume provides more general advice on establishing monitoring systems for freshwater ecosystems. UN Environment hopes to elaborate on other steps in future volumes, to support countries to implement actions to sustainably manage freshwater ecosystems.

It should be stressed that the phases and steps in the Framework do not have to be undertaken in the given order, and it is not necessary to complete one step before moving on to the next. In reality, countries will be at varying levels of progress within each step, and are likely to be working on many of the steps concurrently. Furthermore, there may not be clear boundaries between each step; the steps may be seen as interlinked and interactive elements of a holistic process.

In line with the 'ladder approach' to monitoring that is key to many parts of the SDGs, including many of the targets in SDG 6, the Framework recognizes that different countries will be at varying stages of implementation or development of target setting and ecosystem monitoring. Countries at an advanced stage of the process may use the Framework more as a holistic guide to revise certain aspects of their systems. On the other hand, countries at the early stages of the process, and potentially with limited capacity, may wish to identify certain essential steps for initial reporting, and use this information as the basis for a more detailed process at a later stage, where more of the steps are included. An example of such a starting point is:

INITIATION PHASE

- Agree on a broad draft vision and objective for freshwater ecosystems
- Design preliminary classification of ecosystems

IDENTIFICATION PHASE

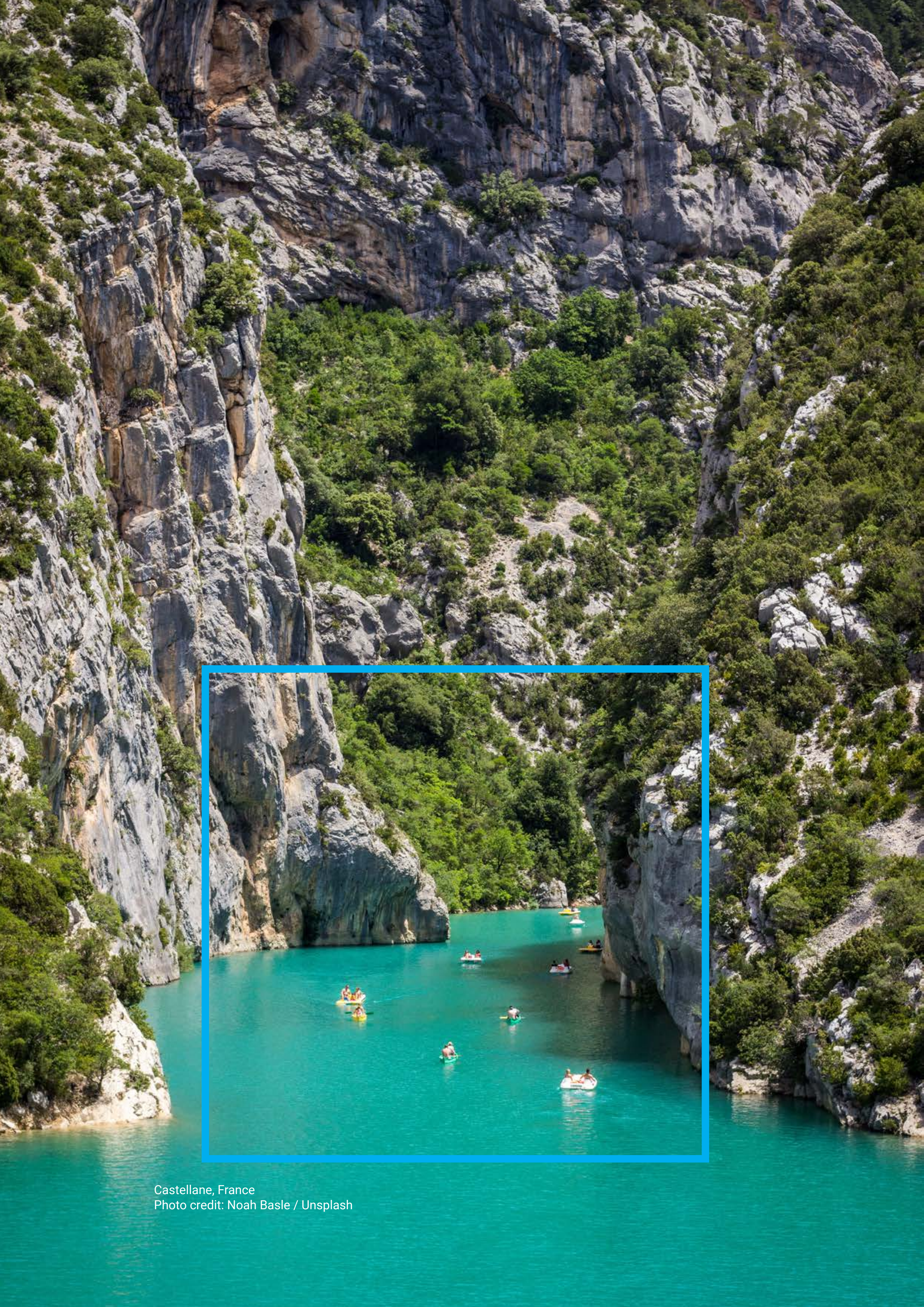
- Identify the known freshwater ecosystems in the country and assign them to drainage basins where possible
- Design preliminary ecological status classes, thresholds and indicators
- Conduct a screening process using available data, expert knowledge and stakeholder input to assign preliminary status classes to ecosystems

Based on the results from the process above, it would be possible to address, refine and populate all the steps as capacity and knowledge increases (Box 2).

South Africa assessed their drainage basins on a coarse scale in 1999 and at a finer drainage basin scale in 2014. Between 1999 and 2014, an increasing number of surveys were conducted and classification and assessment systems were developed – for rivers in particular – to the extent that most of the steps in the Framework have now been addressed. http://www.dwa.gov.za/iwqs/rhp/eco/peseismodel.aspx

Box 2 – Expanding monitoring with expanding capacity in South Africa

Antholzer See, Italy
Photo credit: Eberhard Grossgasteiger / Unsplash



Castellane, France
Photo credit: Noah Basle / Unsplash

3 Designing Classification Frameworks: Ecosystem Types, Services and Potential Indicators (Initiation Phase)

PART A: Detailed Guidance on Designing Classification Frameworks and Setting Ecological Status Classes and Thresholds

Initiation Phase

- Assess Capacity
- Set Vision & Objectives
- Design Classification Frameworks

The 'ecosystem' concept is fundamental to the classification of freshwater ecosystems. It refers to the relationship between living organisms and non-living elements in an area (such as water, air and soil) that interact as a system. Ecosystems do not have fixed boundaries: their size and characteristics are determined by the scientific, management and policy question being addressed. Freshwater ecosystems include habitats and ecological processes contained within rivers and their riparian zones, reservoirs, lakes and wetlands and their fringing vegetation, estuaries and groundwater.

Ecosystems are classified within drainage basins or catchments, which are broadly identifiable according to landscape topography and slope, geomorphology and climate. This approach is valid for surface waters but groundwater bodies may cross the boundaries of several surface drainage basins and may need separate classification.

This step can be broken down into three parts as follows:

- Design a classification framework or typology, to distinguish between different ecosystem types (Section 3.1)
- Identify and differentiate between the likely ecosystem services provided by these ecosystem types (Section 3.2)
- Identify potential indicators that could be used to measure whether the ecosystems can continue to provide services on a sustainable basis (Section 3.3)
- Essentially, in this step the classification systems are developed, which will then be populated in the Identification Phase (Section 6), through the following steps:
- Identify ecosystems and assign to type and ecosystem service
- Set basin context and assign ecosystems to basins
- Carry out desktop screening of data availability, pressures, risks, high value areas, estimation of status, and identification of most at risk and near-natural areas

3.1 Classifying Ecosystem Types[5]

Classifying freshwater ecosystems helps to identify the differences in characteristics and services they provide to society. This also facilitates setting 'natural' or 'baseline' reference conditions for different ecosystem types (see Section 4.1).
Important ecological reasons for classification are:

- Different types of freshwater ecosystems will not look and function the same way even when they are healthy
- The types of indicators that might be appropriate in one type of freshwater ecosystems may not be appropriate for another
- The methods used to sample one type may not be applicable or relevant to another
- Even when the same indicator can be used in different freshwater ecosystem types, the threshold or target values are likely to differ[6]

A hierarchical classification approach

When classifying ecosystem types, it is advisable initially to follow a relatively simple approach, but one which allows for the development of a more detailed hierarchical classification system where necessary and possible. For example, a classification based on a nested hierarchy – i.e. a hierarchy that unfolds from the top with broad, generic descriptions, which at the next level are subdivided into more detailed descriptions that continue to be referenced to the upper level. This can continue down to a level where the limits of capacity and the need for information are reached. The advantage of this approach is that a country can select the level required to adequately classify ecosystem types. The desired level of detail in the classification system may partly relate to the value of ecosystem services, their ecological importance and the pressures on them. For example, if certain species only exist in a particular sub-type of ecosystem, then the classification system should at least capture this ecosystem sub-type. It is also recommended that countries that share drainage basins develop a classification approach that follows the same basic principles and that allows for comparison at a transboundary level.

An ecoregion approach

An established practice in the classification of freshwater ecosystems, if sufficient suitable information is available, is to follow an ecoregion delineation approach. Ecoregions are areas where ecosystems (and the type, quality and quantity of environmental resources) are generally similar.[7,8] Variables such as topography, climate, runoff, geology, geomorphology, soils and natural vegetation are used to define freshwater ecoregions that are essentially subdivisions of an ecosystem in a drainage basin.[9] This approach is applicable to all inland waters.

Useful examples, which can be used as starting points for ecoregion classification, can be found in *A New Map of Standardized Terrestrial Ecosystems of Africa*[10] and *A New Map of Global Ecological Land Units*.[11] These publications contain information on the basic determinants of ecosystem types at a continental scale that can be used to derive aquatic ecosystems within drainage basins.

Additional levels of ecoregion classification can be used when more information is available. Characteristics such as stream size, water regime status, hydro-period and state, temperature, groundwater dependency, hydrological dependency, alkalinity and conductivity may be used

5 Further technical information on the classification of ecosystem types is provided in Sections 2.2 and 4.2 of Volume 4.
6 Section 2.2.1 of Volume 4.
7 Omernik, JM. (1987). Ecoregions of the conterminous United States. Annals of the Association of American Geographers 77:118-125.
8 Abell, R, Thieme, M, Dinerstein, E & Olson, D. (2002). A Sourcebook for Conducting Biological Assessments and Developing Biodiversity Visions for Ecoregion Conservation. Volume II: Freshwater Ecoregions. World Wildlife Fund, Washington, DC, USA
9 Omernik, JM. (2004). Perspectives on the nature and definition of ecological regions. Environmental Management 34 (Supplement 1):27-38.
10 Sayre, R, et al. (2013). A New Map of Standardized Terrestrial Ecosystems of Africa. Washington, DC: Association of American Geographers. 24 pages.
11 Sayre, R, et al. (2014). A New Map of Global Ecological Land Units — an Ecophysiographic Stratification Approach. Washington, DC: Association of American Geographers. 46 pages.

as classifiers if available. The motivation to do this would depend on the available information and the level of priority given to protecting the ecosystem characteristics and services in a country or a defined drainage basin.[12]

It must be noted that the groundwater classification does not necessarily follow the surface water ecoregion classification. Due to geological strata, groundwater may in some cases be underlying several drainage basins and surface ecoregions.

A suggested typology of freshwater ecosystems

Countries that have already established typologies are encouraged to maintain them, or further refine them as necessary. Where a typology does not already exist, the following simple, globally generic and hierarchical inland water typology is proposed as a starting point. It is drawn largely from basic typologies used in existing guidelines (e.g. those of the EU, New Zealand and Australia) as well as water quality classification schemes commonly used in other countries and the extensive discussions that revolved around them. The typology is designed to be an overarching framework that will cover most water bodies, yet remain compatible with national wetland inventories and more complex typologies. It is also structured to allow meaningful comparisons of water quality and ecological characteristics.

At the broadest/highest level, the suggested classification system for freshwater ecosystems is as follows:

1. Running waters: rivers and streams (including estuaries)
2. Standing waters: lakes and reservoirs
3. Vegetated wetlands: vegetation and water dominated ecosystems such as swamps, swamp forests, marshes, peatlands, paddies and mangroves
4. Groundwater bodies: including aquifers

Canals that are predominantly used to deliver water can generally be classified under 'running waters'. These are sometimes referred to as 'aqueducts' and include (for example) irrigation canals and canals constructed for inter-basin transfers. They often cut across drainage divides. Canals that are predominantly used to carry vessels to transport people and goods can generally be classified under 'standing waters'. These are sometimes referred to as 'artificial waterways' and typically run roughly parallel to a natural river or stream and share the same drainage basin.[13]

A well-known classification system is the Ramsar classification system,[14] which has three main categories (and about 45 sub-categories):[15]

- Inland wetlands, which include aquifers, lakes, rivers, streams, marshes, peatlands, ponds, flood plains and swamps
- Coastal wetlands, which include all coastlines, mangroves, saltwater marshes, estuaries, lagoons, seagrass meadows and even coral reefs
- Human-made or artificial wetlands, which include fish ponds, rice-fields, salt pans and storm water retention basins

The 169 countries that are Parties to the Ramsar Convention have to assign nominated 'wetlands' to one of these categories. However, the Ramsar classification system is primarily geared towards the global and regional level, and may not be the most appropriate classification system at the national level. So, while the suggested classification system described below follows a simplified approach, it is nonetheless compatible with the Ramsar approach.

12 Kleynhans, CJ, Thirion, C. and Moolman, J. (2005). A Level I River Ecoregion Classification System for South Africa, Lesotho and Swaziland. Report No. N/0000/00/REQ0104. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa.
13 Alan, DD and Castillo, MM. (2007). Stream Ecology: Structure and function of running waters. Springer.
14 Broadly based on: Cowardin Classification System. Cowardin, L. M.; Carter, V.; Golet, F. C.; LaRoe, E. T. 'Classification of wetlands and deepwater habitats of the United States'. U.S. Department of the Interior, Fish and Wildlife Service.
15 As approved by Recommendation 4.7 and amended by Resolutions VI.5 and VII.11 of the Conference of the Contracting Parties. http://www.ramsar.org/sites/default/files/documents/library/key_res_vii.11e.pdf

Regardless of the type of classification framework, it is important to note that freshwater ecosystem types are usually connected, which has implications on water quantity and quality within a drainage basin. These connections should be identified during the Identification Phase, in the ´Set Basin Context' step (section 6), as they have important management implications. For example, identifying and understanding groundwater–surface water interactions are critical for sustainable management of freshwater ecosystems.

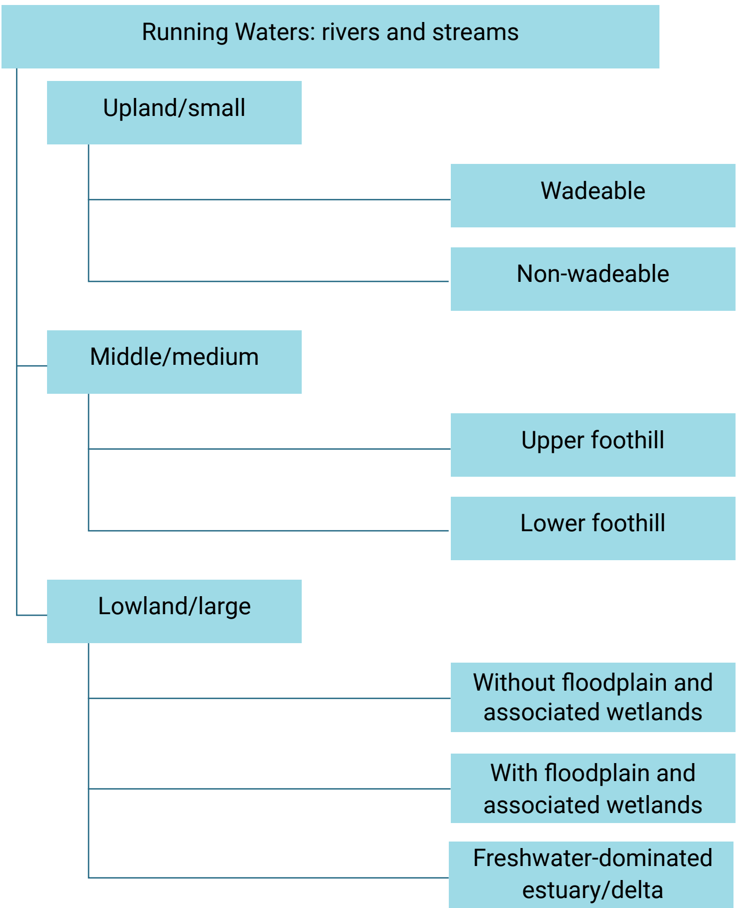
The suggested four main categories can be further broken down as described in the next four subsections.

3.1.1 Running Waters

The following classification determines the relative position of a reach of a river or stream along an upstream-downstream continuum (Figure 2). The classification system is based on basic typologies used in existing guidelines (e.g. those of the EU, New Zealand and Australia), as well as water quality classification schemes used in many countries and in published research.[16]

Additional attributes that can be useful in further classifying any of the above categories include:[17]

- Water regime status (perennial[18]/temporary)
- Groundwater dependency
- Temperature (cold/cool/warm)
- Gross-scale geomorphic features
- Pulsing or stable system



16 Adapted from figure 2.2, Section 2.2.2 of Volume 4.
17 Adapted from figure 2.2, Section 2.2.2 of Volume 4.
18 Flows all year round.

A more detailed classification can be developed by using geomorphic zones, determined by the geomorphology of the stream channel and valley shape.[19] A simplified geomorphic zonation uses 'quantifiable slope zones'[20] to classify rivers and streams. The advantage of going to this next level of detail is that it improves the ability to distinguish ecosystems at a finer scale, making it possible to better assess system condition and initiate restoration. Such approaches can lead to the following categories:

- Source zone: often comprising wetland areas and small streams located in upper mountain areas.
- Mountain headwater stream: A very steep gradient stream dominated by vertical flow over bedrock with waterfalls and plunge pools. Normally first or second order.
- Mountain streams: Steep gradient stream dominated by bedrock and boulders; locally cobble or coarse gravels in pools.
- Transitional stream: Moderately steep stream dominated by bedrock or boulder.
- Upper foothill stream or river: Moderately steep, cobble-bed or mixed bedrock/cobble-bed channel.
- Lower foothill stream or river: Lower gradient, mixed-bed, alluvial channel with sand and gravel dominating the bed; locally may be bedrock controlled.
- Lowland river: Low gradient, alluvial, fine-bed channel.[21] May be confined, but fully developed meandering pattern within a distinct flood plain develops in unconfined reaches where there is an increased silt content in bed or banks.

Estuaries and Coastal Deltas

Estuaries are bodies of water within which freshwater from rivers and streams mixes with saltwater from the ocean. They are typically included in freshwater classification systems as their status is usually dependent on upstream activities, and they provide important habitats for many species.

A range of classification systems for estuaries exist, with no single approach widely endorsed.[22] As estuaries represent the interface between the freshwater and marine environments, the classification system will typically depend on the objective of classification – for example:

- To identify types of estuaries most at risk from pollution, e.g. nutrients
- To identify habitat types useful for fisheries management

Or they may simply be based on physical attributes – for example:

- Geology (how they were formed) – which can affect habitats
- Types of freshwater/saltwater circulation or mixing patterns – which has implications for water quality and habitat types

In the context of the Framework for Freshwater Ecosystem Management, a system that classifies by type of mixing may be most useful. This could include:[23]

- salt-wedge: least mixed; rapidly flowing river; weak tidal currents
- slightly stratified / partially mixed: salinity generally greater at lower levels
- vertically mixed / well-mixed: generally low river flow; moderate to strong tidal currents
- fjord: mostly freshwater in the estuary due to a shallow barrier near the ocean, which results in very little mixing

19 Rosgen, DL. (1994). A classification of natural rivers. Catena. 22: 169-199.
20 Rowntree, KM and Wadeson, RA. (1999). A Hierarchical Geomorphological Model for the Classification of Selected South African Rivers. Water Research Commission Report No. 497/1/99. Pretoria, Water Research Commission. 334 pp.
Moolman, J, Kleynhans, CJ. Thirion, C. (2002). Channel Slopes in the Olifants, Crocodile and Sabie river catchments. Department of Water Affairs and Forestry, Institute for Water Quality Studies Internal Report No.: N/0000/00REH/0102. Pretoria. Department of Water Affairs and Forestry. 41 pp.
21 The pattern of seasonal flow of water in a river is known as the 'river regime': https://www.quora.com/What-is-meant-by-regime-of-river
22 Kurtz, JC and Hagy, JD. (2012). Classification for Estuarine Ecosystems: A Review and Comparison of Selected Classification Schemes. In: Jordan S. (Ed). Estuaries : classification, ecology, and human impacts. Nova Publishers.
23 https://oceanservice.noaa.gov/education/kits/estuaries/estuaries05_circulation.html

Coastal deltas are land formations that are created by the deposition of sediment carried by a river as it slows and reaches the ocean marine waters. A tidal freshwater delta is a sedimentary deposit formed at the boundary between an upland stream and an estuary, in the region known as the sub-estuary.[24]

Related to estuaries are coastal lagoons (e.g. coastal bays, coastal lakes, coastal ponds). Coastal lagoons are shallow basins between the mainland coast and the landward side of a barrier such as an island, spit, reef or sandbank.[25] They may be partially or totally enclosed and are considered salt marsh estuaries driven by tidal circulation. This is in contrast to riverine estuaries, which have a freshwater river source at their head.[26] Coastal lagoons are more likely to be classified as 'standing waters'.

3.1.2 Standing Waters

At the most basic level, it is recommended that standing waters are classified into:
- Natural lakes: generally sparsely vegetated (e.g. less than 30 per cent vegetation) and generally with a minimum size (e.g. 8 or 16 hectares) ,
- Reservoirs: either created in a location where no waterbody existed before, or by substantially changing an existing waterbody

There are a number of more detailed classification systems for lakes. The most common include:
- By origin: 11 major types including glacial, tectonic, volcanic, shoreline and anthropogenic.
- According to thermal stratification (mixing): this is an important form of classification for ecosystems as the degree of mixing is a major control on the animal and plant life in the lake, and determines the distribution of oxygen and nutrients.
- According to seasonal variation of lake level and volume: there are two major types: ephemeral (fluctuates between dry and wet season; if it fills and dries seasonally it is known as 'intermittent') and perennial (has water throughout the year and level does not fluctuate dramatically). Ephemeral lakes are known by different names in different countries.
- Hydrological connectivity: e.g. isolated, located along rivers, groundwater-dependent, etc.
- According to natural chemical or physical characteristics including:
  - pH level: acidic or alkaline
  - Salinity: salt lakes, salt pans or very low electrical conductivity
  - Nutrient content
  - Turbidity/colour/sediment

Typically, these approaches to lake classification are combined in some form to suit the local situation, and different characteristics may be used to classify lakes. The selection of characteristics depends on the types of lakes most commonly found in the country and the level of information available. The most appropriate characteristics should be identified by scientists familiar with lakes in the country.[30]

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24 http://pasternack.ucdavis.edu/research/projects/tidal-freshwater-deltas/
25 Kennish, MJ. (2016). Coastal lagoons. In: Kennish, MJ (Ed). Encyclopedia Of Estuaries. Springer.
26 Howard, J. D., and Frey, R. W., 1985. Physical and biogenic aspects of backbarrier sediment systems, Georgia coast, USA. Marine Geology, 63, 77–127.
27 Cowardin Classification System. Cowardin, L. M.; Carter, V.; Golet, F. C.; LaRoe, E. T. "Classification of wetlands and deepwater habitats of the United States". U.S. Department of the Interior, Fish and Wildlife Service.
28 https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/nri/?cid=nrcs143_014127
29 Wetzel, RG. (2001). Limnology: Lakes and River Ecosystems. Academic Press. 3rd Edition.
30 Likens, G (Ed). 2009. Encyclopedia of inland waters. Academic Press.

Lakes can, in effect, be grouped as a sublevel of the ecoregion within which they reside.[31] Similarly, highly distinct lakes and endorheic (closed-basin) systems may justify the creation of an ecoregion-within-an-ecoregion.[32]

There are a number of important considerations in classifying lakes:[33]

- The need to define reference conditions to make comparisons between the natural and present-day ecological status classes. Natural lakes should be classified based on the underlying properties of lakes independent of human influence.
- A classification should also reflect differences in the biota of the ecological status classes. For example, a deep lake might have a fish assemblage different from that of a shallow lake, and classification based on the biota should distinguish between the two types of systems.

Reservoirs are usually formed by the damming of river valleys or by the storage of water in off-channel structures. In river valleys, three reservoir zones along the longitudinal gradient may be distinguished:[34]

- A narrow riverine zone at the inflow that has a high variation in water temperature, sediment movement and particulate water turbidity
- A transitional zone with decreased flow velocities, turbidity and sedimentation
- A lacustrine zone upstream of the dam wall that may have characteristics comparable to natural lakes in terms of stratification and morphological interactions

Reservoirs fall within river ecosystems, and ecoregion characteristics and classification will be determined by the drainage basin upstream of the wall as well groundwater.

In the absence of adequate national data, the Global Lakes and Wetlands Database[35] can serve as a basis to assess the significance of lakes due to the large number of such ecosystems in many countries. Priority ranking of lakes according to ecosystem services and ecological importance, as well as technical capacity, will determine at what scale and detail lake ecological status will be assessed.

3.1.3 Vegetated Wetlands

Wetlands are among the most productive ecosystems in the world – comparable to rainforests. While covering only 6 per cent of the Earth's surface,[36] wetlands provide a disproportionately high number of ecosystem services that benefit, sustain and support the environmental, social and economic well-being of people.

Five major wetland types are generally recognized[37] and used in many countries around the world:[38]

- Riverine: wetlands along rivers and streams
- Lacustrine: wetlands associated with lakes
- Palustrine: dominated by vegetation – e.g. marshes, swamps and bogs
- Estuarine: including deltas, tidal marshes and mudflats, and mangrove swamps
- Marine: coastal wetlands including coastal lagoons, rocky shores, seagrass beds and coral reefs

31 Gallant, AL, Whittier, TR, Larsen, DP, Omernik, JM and Hughes, RM. (1989). Regionalization as a tool for managing Environmental resources. USEPA. Oregon. EPA/600/3-89/060.
32 Abell, R, Thieme, M, Dinerstein, E, and Olson, D. (2002). A Sourcebook for Conducting Biological Assessments and Developing Biodiversity Visions for Ecoregion Conservation. Volume II: Freshwater Ecoregions. World Wildlife Fund, Washington, DC, USA.
33 USEPA (1998). Lake and Reservoir Bioassessment and Biocriteria: Technical Guidance Document. Washington, DC. EPA 841-B-98-007
34 Wetzel, RG. (2001). Limnology: Lakes and River Ecosystems. Academic Press. 3rd Edition.
35 http://www.worldwildlife.org/pages/global-lakes-and-wetlands-database
36 http://wwf.panda.org/about_our_earth/about_freshwater/intro/
37 C. Max Finlayson, CM and Van Der VALK, AG. (1995). Classification and inventory of the world's wetlands. Springer Science.
38 For example, in Australia: Aquatic Ecosystems Task Group for Department of Sustainability, Environment, Water Population and Communities (2012). Aquatic Ecosystems Toolkit Module 2: Interim Australian National Aquatic Ecosystem (ANAE) Classification Framework. Available at: http://www.environment.gov.au/resource/aquatic-ecosystems-toolkit-module-2-interim-australian-national-aquatic-ecosystem-anae

In the simplified classification system suggested in this step, palustrine or vegetated wetlands can be considered at the same level as running waters and standing waters. Riverine and estuarine wetlands can be considered under 'running waters', and lacustrine wetlands (and coastal lagoons) can be considered under 'standing waters'. Most marine wetlands are not relevant for a freshwater ecosystems classification system.

If further sub-classification is desired, a hydrogeomorphic approach is often used. Using geomorphic position and hydrological characteristics, an early classification system defined seven wetland classes: depressional wetlands, wetlands, mineral flats, organic flats, tidal flats, lacustrine fringe and slope wetlands.[39] This classification system laid the foundation for efforts to develop methods for assessing the physical, chemical and biological functions of wetlands. Strengths of the classification include clarification of the relationship between hydrology, geomorphology and wetland function, as well as the open structure, which allows adaptation to various types of wetlands and geographic regions in a country. This approach forms the basis of many wetland classification systems.[40,41,42]

It is also worth identifying the extent to which wetlands are groundwater-dependent, as this can affect management actions (see Figure 3).

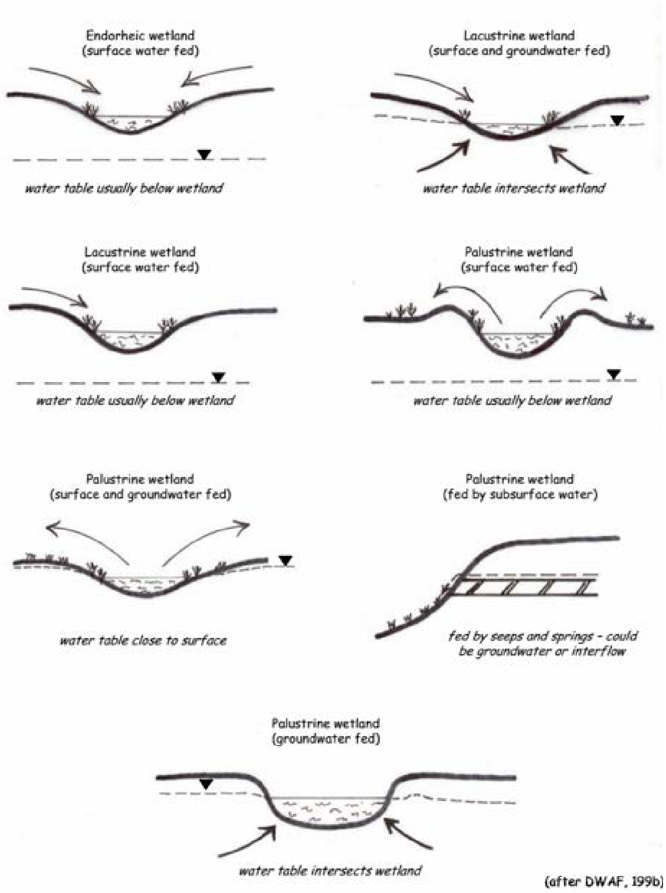

Figure 3 - Examples of wetland classification based on the contributions from surface and groundwater[43]

39 Brinson, M.M. (1993). A Hydrogeomorphic classification for wetlands. Wetlands Research Program Technical Report WRP-DE-4. US Army Corps of Engineers, Washington, DC.
40 Brinson, MM, Hauer, FR, Lee, L C, Nutter, W L., Rheinhardt, RD, Smith, RD & Whigham, D. 1995. A guidebook for application of hydrogeomorphic assessments to riverine wetlands. Technical Report WRP-DE-11, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
41 Ollis, DJ, Snaddon, CD, Job, NM and Mbona, N. (2013). Classification System for Wetlands and other Aquatic Ecosystems in South Africa. User Manual: Inland Systems. SANBI Biodiversity Series 22. South African National Biodiversity Institute, Pretoria
42 Semeniuk, CA and Semeniuk, V. (1995). A geomorphic approach to global classification for inland wetlands. In: Finlayson C.M. and van der Valk A.G. (editors), Classification and Inventory of the World's Wetlands. Kluwer Academic Publishers
43 DWAF (1999) Resource directed measures for protection of water resources Vol 4 Wetland ecosystems Version 1.0; Department of Water Affairs and Forestry, Pretoria.

An ecoregion approach may also be useful in the classification of certain types of wetlands such as high-altitude wetlands. However, wetlands are sometimes considered azonal ecoregions that can occur in any zone where the appropriate geomorphology exists.[44]

3.1.4 Groundwater [45,46,47]

Groundwater plays a critically important role in the functioning of most freshwater ecosystems, as well as constituting an ecosystem in its own right with distinct biota and abiotic characteristics.[48,49,50,51]

Groundwater is the basis of aquifer-dependant ecosystems,[52,53,54] and can support the following:

- River base flow systems: Groundwater base flow is often essential for aquatic biota and riparian ecosystems that exist in or adjacent to streams. Base flow during the dry season and drought periods is often a determining factor in the type of biota present.
- Aquifer and cave ecosystems: Aquatic ecosystems that occupy caves or aquifers. Such systems may harbour uniquely adapted biota.[55]
- Wetlands: The aquatic communities and fringing vegetation of wetlands and lakes may be dependent on groundwater contributions.
- Terrestrial fauna: Native animals may rely directly on groundwater as drinking water but do not rely on it as habitat. This occurs in settings such as types of springs that are surface expressions of groundwater[56] and in sandy-bed seasonal rivers where subsurface water may become available due to excavation by some animals (e.g. elephants).
- Estuarine and near-shore marine ecosystems: Coastal, estuarine and near-shore marine plant and animal communities whose ecological function has some dependence on discharge of groundwater.

The source and characteristics of groundwater, such as volume and water quality, varies according to the rock types and their permeability and porosity to water. These factors are used to classify various groundwater types:[57]

- Aquifer: The term used where a rock type is highly permeable and thus able to transmit significant volumes of water
- Perched Aquifers: A saturated groundwater body that overlies an unsaturated zone
- Aquitard: Where a rock type has low permeability, it can only transport small quantities of water which may nevertheless be significant for flow in a groundwater system
- Aquiclude: Where a rock type has very low permeability it will transmit very limited amounts of water, although it may actually contain large quantities of groundwater
- Aquifuge: Rock types with a negligible permeability and porosity will not transmit any water and do not contain any water

44 Jepson, P and Whittaker, RJ. (2002). Ecoregions in context: a critique with special reference to Indonesia. Conservation Biology. 16: 42-57.
45 Kafri, U. and Yechieli, Y. (2010) Groundwater Base Level Changes and Adjoining Hydrological Systems. Springer-Verlag.
46 Jones, JB and Mulholland, PJ (Eds.) (1999_. Streams and ground waters. Academic Press.
47 http://www.ramsar.org/search?search_api_views_fulltext=groundwater
48 Ribeiro, I, Stigter, TY, Chambel, A, Condesso de Melo, AMT, Monteiro, JP and Albino Medeiros, A (Eds.) (2013). Groundwater and Ecosystems. IAH - Selected Papers on Hydrogeology. CRC Press/Balkema
49 Winter, TC, Harvey JW, Franke, LF and Alley, WM. (1998). Ground Water and Surface Water: A Single Resource. U.S. Geological Survey Circular 1139.
50 Gibert, J, Danielopol, DL and Stanford, J (Eds.) (1994). Groundwater ecology. Academic Press.
51 Stein, H, Griebler, C, Berkhoff, S, Matzke, D, Fuchs, A and Hahn, HJ. (2012). Stygoregions – a promising approach to a bioregional classification of groundwater systems. www.nature.com/scientificreports. SCIENTIFIC REPORTS | 2: 673 | DOI: 10.1038/srep00673
52 https://wetlandinfo.ehp.qld.gov.au/wetlands/ecology/aquatic-ecosystems-natural/groundwater-dependent/
53 Sinclair Knight Merz. (2001). Environmental water requirements for groundwater dependent ecosystems; Environmental flows initiative technical report No. 2, Commonwealth of Australia, Canberra.
54 Colvin, C, le Maitre, D, Saayman I, and Hughes, S. (2007). Aquifer Dependent Ecosystems in Key Hydrogeological Typesettings in South Africa WRC Report No TT 301/07. South Africa.
55 Gibert J, Culver DC, Dole-Olivier MJ, Malard F. and Christman MC. (2009). Assessing and conserving groundwater biodiversity: synthesis and perspectives. Freshw Biol 54:930–941.
56 Parsons, R. (2004). Surface Water – Groundwater Interaction in a Southern African Context. WRC Report No. TT 218/03. South Africa.
57 Nonner, JC. (2003). Introduction to hydrogeology. A.A. Balkema Publishers.

Other attributes of groundwater that play an important role in their ecosystem function include:[58]

- The rate and volume of supply of groundwater
- For unconfined aquifers,[59] the depth below the surface of the water table (level)
- For confined aquifers,[60] the potentiometric head (hydraulic pressure) of the aquifer and its expression in groundwater discharge areas
- The chemical quality of groundwater: pH, salinity and other potential constituents, such as nutrients and contaminants

3.2 Defining Potential Ecosystem Services per Ecosystem Type[61]

Due to their natural characteristics, different freshwater ecosystem types provide different kinds of services to humankind.[62] It follows that different ecosystems will have different capacities and limits to sustainably deliver particular services. The human species, while buffered against environmental changes by culture and technology, is fundamentally dependent on the flow of ecosystem services (Box 4).

> "Homo sapiens is not an external disturbance, it is a keystone species within the system. In the long term, it may not be the magnitude of extracted goods and services that will determine sustainability. It may well be our disruption of ecological recovery and stability mechanisms that determines system collapse." O'Neill, R.V. (2001). Is it time to bury the Ecosystem concept? Ecology, 82:3275–3284.

Box 4 Human dependency on ecosystems

Depending on the scale at which a particular ecosystem type is classified, it is possible to identify the potential services that an ecosystem can provide. Assessing the importance of particular services per ecosystem type will depend on the degree to which these services can be measured or estimated. Conceptually, the broad ecosystem types described in section 3.1 represent different environmental conditions that will provide different ecosystem services and in different quantities.

Generally, ecosystem services are the direct and indirect contributions of ecosystems to human well-being. They include:[63]

- Provisioning services: The products obtained from ecosystems such as food, fresh water, wood, fibre, genetic resources and medicines
- Regulating services: The benefits obtained from the regulation of ecosystem processes such as climate regulation, natural hazard regulation, water purification and waste management, erosion control, pollination and pest control
- Habitat services: The importance of ecosystems to provide habitat for migratory species and to maintain the viability of gene-pools
- Cultural services: The non-material benefits that people obtain from ecosystems such as recreation and mental and physical health, tourism, aesthetic appreciation and inspiration for culture, art and design, and spiritual experience

58 Sinclair Knight Merz. (2001). Environmental water requirements for groundwater dependent ecosystems; Environmental flows initiative technical report No. 2, Commonwealth of Australia, Canberra.
59 "Unconfined aquifers occur in permeable geological formations where the water table can move freely up or down, without restriction": Parsons, R. (2004). Surface Water – Groundwater Interaction in a Southern African Context. WRC Report No. TT 218/03. South Africa.
60 Confined: "Aquifers overlain by material with a hydraulic conductivity significantly lower than that of the aquifer": Parsons, R. (2004). Surface Water – Groundwater Interaction in a Southern African Context. WRC Report No. TT 218/03. South Africa.
61 The 'utilitarian' versus 'eco-centric' approaches to ecosystem management, and reconciling them through the concept of 'ecosystem health', is described in Section 2.3 of Volume 4.
62 MA (2005): https://cices.eu; http://www.teebweb.org; https://seea.un.org
63 http://www.teebweb.org/resources/ecosystem-services/, http://doc.teebweb.org/wp-content/uploads/Study%20and%20Reports/Reports/Ecological%20and%20Economic%20Foundations/TEEB%20Ecological%20and%20Economic%20Foundations%20report/TEEB%20Foundations.pdf

Understanding the different types of ecosystem services that may be provided by each ecosystem type helps both with the appreciation of ecosystem services in the context of sustainable development, and with designing the monitoring framework to help track the capacity of the ecosystems to continue providing those ecosystem services.

Table 1 below illustrates the breadth of the types of ecosystem services that may be provided by the broad categories of ecosystem type. As can be seen from the table, each ecosystem type has the potential to provide most of the ecosystem services. Whether they do or not depends on national and local circumstances. At the national level, the table may be further refined by indicating the likelihood or significance of an ecosystem type providing an ecosystem service. Some services may be more likely to be provided, or provided to a greater extent, in one ecosystem type compared to another. For example, while estuaries can provide water supply if it is desalinated, lakes provide a much more common and readily available source of water.

Table 1 - Examples of ecosystem services potentially provided by the broad ecosystem types [64]

Category		ECOSYSTEM TYPE					
	TYPE OF SERVICE	Rivers	Riparian Zones[65]	Wet-lands	Lakes	Estuaries	Ground-water
PROVISIONING	**Food** (e.g. fish, game, fruit)	X	X	X	X	X	
	Water (e.g. for drinking, irrigation, cooling)	X	X	X	X	X	X
	Raw Materials (e.g. fibre, timber, fuelwood, fodder, fertilizer)	X	X	X			
	Genetic resources (e.g. for crop-improvement and medicinal purposes)	X	X	X	X	X	
	Medicinal resources (e.g. biochemical products, models and test-organisms)	X	X	X	X	X	
REGULATING	**Air quality regulation** (e.g. capturing (fine) dust, chemicals, etc.)	X	X	X	X	X	
	Climate regulation (incl. C-sequestration, influence of vegetation on rainfall)		X	X	X		
	Moderation of extreme events (eg. storm protection and flood prevention)	X	X	X	X	X	
	Regulation of water flows (e.g. natural drainage, irrigation and drought prevention)	X	X	X	X	X	X
	Wastewater treatment (especially water purification)	X	X	X	X	X	
	Erosion prevention		X	X		X	
	Maintenance of soil fertility (incl. soil formation)	X	X	X			
	Pollination		X	X	X	X	
	Biological control (e.g. seed dispersal, pest and disease control)	X	X	X	X	X	
HABITAT	**Maintenance of life cycles of species** (incl. nursery service)	X	X	X	X	X	
	Maintenance of genetic diversity (especially in gene pool protection)	X	X	X	X	X	X

Contd...

64 Typology of ecosystem services taken from 'The Economics of Ecosystems and Biodiversity' (TEEB): http://www.teebweb.org/resources/ecosystem-services/, http://doc.teebweb.org/wp-content/uploads/Study%20and%20Reports/Reports/Ecological%20and%20Economic%20Foundations/TEEB%20Ecological%20and%20Economic%20Foundations%20report/TEEB%20Foundations.pdf

65 This refers to the interface between freshwater habitats (normally flowing waters) and the terrestrial landscape. In many countries riparian zones would be considered to be part of the freshwater ecosystem. Gregory, SV, Swanson, FJ, McKee, WA and Cummins, KW. (1991). An ecosystem perspective of riparian zones. BioScience 41:540-551

CULTURAL	Recreation and mental and physical health	X	X	X	X	X	X
	Tourism	X	X	X	X	X	X
	Aesthetic appreciation and inspiration for culture, art and design	X	X	X	X	X	
	Spiritual experience and sense of place	X	X	X	X	X	X

3.3 Identifying Potential Indicators Important for the Provision of Ecosystem Services

Following the classification framework of ecosystem types and the associated ecosystem services, this step involves the identification of potential indicators that could be used to measure the sustainable provision of ecosystem services. In the context of this guide, an indicator is a measure that can be used to characterize the ecological status of an ecosystem. In other words, if the indicator values are impacted on or changed by human activity, then this may lead to a change in the provision of ecosystem services. The primary reason for undertaking this step is to make an initial assessment of important indicators that can be used to monitor the sustainable management of ecosystems. This information can be used:

- to inform the desktop screening, which compiles existing data and information on the most important indicators that may affect ecosystem function (Identification Phase)
- to inform the selection of key indicators to track changes in ecological status (Assessment Phase)
- as a communication tool for discussions with stakeholders (Response Phase)
- to prioritize ecosystem services and the management actions necessary to maintain them (Response Phase)

For example, if sedimentation of reservoirs is an important but negative issue in a country, then an important ecosystem service to be considered for management could be erosion control in upstream areas; in this case, a key indicator could be the existence/extent of vegetation in wetlands and riparian zones (along rivers and streams).
It is not practical to list all indicators that could be relevant to ecosystem services in this volume, but they can be broadly classified as follows:

- Water quantity: volume and timing of flows, water depth and velocity
- Water quality: nutrients (e.g. from diffuse sources such as run-off from agriculture, or point sources such as wastewater discharges, toxicants, oxygen levels, acidity, temperature)
- Spatial extent: of wetlands, lakes, riparian zones
- Habitats: the 'home' and habitat features biota need for survival (cover) and during their life cycle (spawning, breeding, nursery areas, etc.) – e.g. rocky substrate, high velocity water, riparian vegetation, deep pools, etc.
- Biological: fish, benthic macroinvertebrates, microbes (e.g. E. coli), aquatic plants (macrophytes), etc.

In addition to the 'state' of freshwater ecosystems, it can be useful, in many cases, to monitor the pressures on them.[66] For example, monitoring the degree to which wastewater is treated, as measured in SDG indicator 6.3.1, can help to identify the source of pollution. Monitoring the 'disconnectivity' in freshwater ecosystems – for example by analysing the presence of infrastructure along a river – can give an indication of the likely level of disturbance in that ecosystem. Monitoring water withdrawals from ecosystems, as measured in SDG indicator 6.4.2, can help to identify where withdrawals are not sustainable. Monitoring the pressures on ecosystems can help to link the 'state' with the 'cause' of that state, and therefore greatly facilitate management actions to address the situation.

66 In Volume 4, a distinction is made between 'pressures' and 'stressors' (see Section 2.4 of Volume 4). In this volume, no distinction is made: the term 'pressures' is used to cover both aspects.

As a minimum, countries should aim to report on the indicators identified in SDG indicator 6.6.1, 6.3.1 and 6.3.2. at the most basic level. These include the first three of the above four categories; and at a more advanced level of monitoring, also include biological indicators. These are addressed in Table 2 below, including the most likely causes to changes in the indicators, as well as the impacts of these changes on ecosystem services.

Table 2 - Basic indicators associated with the SDGs (6.3.2 and 6.6.1), potential pressures and impacts on ecosystem services.

CATEGORY	INDICATOR (INCL. DIRECTION OF CHANGE FROM NATURAL)	PRESSURES	CONSEQUENCES: IMPACT ON ECOSYSTEM SERVICES	RELEVANT ECOSYSTEMS
WATER QUANTITY AND SPATIAL EXTENT (SDG 6.6.1)	Decrease in quantity and spatial extent	Usually due to overuse – e.g. direct surface water and groundwater abstraction (SDG 6.4), or destruction of wetlands due to agricultural or urban expansion	Decrease in base flows and natural floods. Loss of biological functions that will impact on instream and riparian ecological state, with a decrease in riparian material production (food, building materials, fuel, etc.) and instream food production (e.g. fish), fragmentation of biological communities and loss of viability of populations. Potential decrease in the inundation of flood plains and nutrient and sediment transport to the floodplain. May result in decrease of fish production and decrease in soil quality needed for crop cultivation. Influence on the freshwater requirements of estuaries and consequent impact on fish production.	Rivers and streams, riparian wetlands, floodplains, lakes and reservoirs, estuaries, groundwater ecosystems
WATER QUANTITY AND SPATIAL EXTENT (SDG 6.6.1)	Increase in quantity (intermittent/ seasonal/ perennial for rivers and palustrine wetlands)	Usually due to changes in natural flow regime, such as reservoir releases or inter-basin transfer into a river, reservoir or lake.	Increased bank and instream erosion and movement of sediments. Deposition of sediments in slow flowing sections (pools) may cause loss of habitat volume for instream biota. Bed armouring (removal of fine sediment due to increased flows) and change in substrate characteristics. Increased risk of invasive plant encroachment in riparian zone. Detrimental changes in the functions and characteristics of the zone. Results in a change in ecological processes such as food production, and wood production for fuel and building material. Fragmentation of biological communities and potential loss of viability of food (fish) production. Disruption of the migration corridor for biota and the runoff buffering effect of the zone that controls erosion and surface water quality. Introduction of undesirable biota through inter-basin transfers and purposeful introduction of such biota into reservoirs (and lakes). Impact in freshwater–seawater balance in estuaries with possible impact on food production and fish spawning.	Rivers and streams, riparian wetlands,

Contd...

WATER QUALITY (SDG 6.3.2 & 6.6.1)	Increase in nutrients	Originates from point sources (urban areas and industries, fish farms) (SDG 6.3.1) and non-point sources (e.g. urban runoff, agricultural areas and fish cage aquaculture in lakes and reservoirs)	May accelerate biochemical rates – e.g. excessive algal growth that may result in development of water column oxygen concentration variations (especially anaerobic conditions) and production of algal toxins. May have an extreme impact on aquatic biotic assemblages and influence food production population. May enhance growth of riparian vegetation (including fringing or marginal vegetation) and growth of undesirable aquatic macrophytes, and enable the establishment of undesirable and tolerant aquatic fauna. A decrease in natural flow volume can potentially exacerbate the impact of increased nutrients due to a loss of assimilative capacity and dilution of nutrients.	lacustrine wetlands, reservoirs, lakes, estuaries
	Oxygen levels	Increases in oxidizable material results in high chemical oxygen demand (COD) from diffuse sources (e.g. runoff) or point sources (e.g. wastewater discharge) from urban and agricultural areas and certain industries. Also closely related to the enhanced biological activity of aquatic organisms due to an increase in nutrients.	Decreases in oxygen can modify the natural aquatic assemblages and favour low oxygen-tolerant biota. Eventually this will influence food fish populations, with a decrease in desirable species and biodiversity. High flow releases from a reservoir can result in high turbulence, resulting in dissolved gas super-saturation that is detrimental to some fish species (i.e. 'gas bubble disease').[67]	Rivers and streams, lakes, reservoirs, wetlands and estuaries
	Acidity	pH decrease can originate from acid mine drainage, and industrial processes and acid rain. Increase can be a result of industrial processes as well as biological activity in some standing water bodies indirectly due to increases in nutrient concentrations.	Decreases can increase the toxicity of metals and result in the mortality of all but the most tolerant biota. Water can be rendered unusable without intensive treatment. Increases in pH can be detrimental for aquatic biota and cause physical damage to sensitive fish populations, with eventual impact on fish food production and the shifting of a fish assemblage composition to tolerant species and a loss in biodiversity.	Rivers and streams, wetlands, lakes, reservoirs, estuaries, groundwater
	Electrical Conductivity (EC)	Industries, urban areas, mines, agricultural runoff (SDG 6.3.1) and saltwater intrusion due to over-extraction of groundwater.	Increases generally relate to an increase in salinity. These may cause a disruption in the populations of sensitive biota. The constituents of the salts that increase EC may also be toxic to some biota (e.g. some magnesium salts). Depending on the degree of EC change and the salts involved, the aquatic food chain can be changed, resulting in a decrease in desired fish species populations and biodiversity loss.	River, streams lakes, reservoirs, wetlands, estuaries, groundwater

67 Weitkamp, DE. and Katz, M. (1980). A Review of Dissolved Gas Supersaturation Literature, Transactions of the American Fisheries Society, 109:6, 659-702

Biological indicators

Depending on the ecosystem type, size and biota, some biological indicators may provide a rapid and cost-effective way to monitor ecosystem integrity. For 'natural' or 'near-natural' ecosystems, it may be particularly important to monitor biological indicators, to be able to set the natural baseline condition. However, regularly monitoring the full suite of biological indicators (e.g. fish, macro-invertebrates, diatoms, instream and riparian vegetation) is often more labour and capacity intensive than monitoring physical and chemical indicators, and is often only included in more advanced monitoring systems. The general principle is that plants and animals in ecosystems have adapted to live in balanced, dynamic communities under preferred morphological, physical and chemical conditions. When these conditions change, either naturally or as a result of human activities, the plants and animals become stressed and either move away or struggle to survive, and may even disappear. The presence or absence of certain species, or combinations of species, can therefore indicate a change in the ecological status of freshwater ecosystems (below the desired condition). For example, species intolerant of no-flow conditions or modified water quality conditions may give an indication of modified environmental conditions. Stress also has a natural dimension: the natural stress regime provides the template within which species and communities evolved. This determines the resilience and the ability of a biological assemblage to recover from natural disasters such as droughts and floods. If the duration and extent of human induced stresses exceed the natural stress regime, the ecosystem can be permanently damaged.

The monitoring of biological indicators is especially valuable when the responses of biota to physical and chemical conditions are well known and based on quantitative data. Various biological indicators are often combined to form indices to give an integrated picture of ecological status (see Section 4.2 and SDG 6.6.1 methodology). The selection of biological indicators to assess ecosystem health will depend on the level of local scientific information and capacity.

Sapa, Vietnam
Photo credit: Zulfahmi Khani / Unsplash

4 Setting Ecological Status Thresholds and Targets: Defining Status Classes, Selecting Indicators and Thresholds, and Setting Management Targets (Assessment Phase)

Assessment Phase
- Set Ecological Status Thresholds & Targets
- Monitor
- Evaluate & Report

The Assessment Phase involves setting targets for ecological status, monitoring the status of ecosystems using relevant indicators (Section 7), and finally evaluating the data and reporting on the status of ecosystems (not described in detail in this report). For the sustainable management of freshwater ecosystems, it is essential to define the desired state or condition of each ecosystem, referred to as 'ecological status' in this volume. Progress towards a desired ecological status can be assessed based on monitoring results using quantifiable indicators. If monitoring results show that the desired state has not been reached, then this can lead to an assessment of the causes of the problem, and ultimately initiation or revision of management actions to rectify the situation. In essence, formulated targets enable the interpretation of monitoring results.

The process for setting targets for ecological status is broken down into the following parts:
- Defining ecological status classes
- Selecting indicators
- Setting threshold values for indicators for each ecological status class
- Setting targets for the ecological status of each ecosystem

The first three parts are very closely linked and are likely to be undertaken simultaneously. The last part is essentially a sociopolitical process, which is heavily influenced by the economic and ecological context. Involvement of stakeholders is therefore essential.

The process for setting targets should be undertaken within the context of the agreed vision outlined in the Initiation Phase, and is closely linked to the screening process in the Identification Phase, where desktop, stakeholder and expert information is collated and evaluated to make a first estimate of the relative ecological status. Setting threshold values for indicators is also closely linked to existing monitoring data in natural or near-natural ecosystems.

4.1 Defining Ecological Status Classes[68]

Knowledge of ecological status classes can be used to:

- Formulate present and future objectives concerning the desired status of ecosystems
- Enhance the awareness of authorities and stakeholders
- Trigger certain management actions
- Compare the status of different ecosystems
- Report changes in status over time

A diverse range of classification systems exist for describing ecological status, but they generally include a 'good' class representing high ecosystem integrity or natural conditions, and a 'poor' class representing extreme ecosystem impairment.[69,70]

The number of classes partially depends on the quantity and quality of information that is available, as well as the objective of communicating status to stakeholders and influencing management actions. Generally, between four and six classes are recommended, to ensure there is sufficient nuance to track progress over time (i.e. a minimum of four classes), yet avoiding unnecessary or meaningless over-complication which may hamper communication (i.e. a maximum of six classes).[71,72]

Usually, the extremes in ecological status are conceptually relatively straightforward to determine. Natural or near-natural and (at the other extreme) badly degraded or seriously modified ecosystems are fairly distinct. In between and relative to these extremes, a number of classes on a declining gradient and relative to each other are distinguished using a descriptive numerical (1, 2, 3, etc.) or alphabetical (A, B, C, etc.) notation. For communication purposes, these classes are often colour coded.

An example of an ecological status classification system is given in Table 3 below. This reflects the classification system used in SDG 6.6.1. There are several ways of describing each class, based on different attributes. For example, the description may relate to ecosystem extent, function and services, which could be quantified in a percentage deviation from the natural condition. Note that these percentages are prescribed for reporting on SDG indicator 6.6.1, but there may be national circumstances which would require an amendment of the values for non-SDG reporting. The description may also relate to sustainability. While the percentage deviations for the overall ecological status are generic, the thresholds set for particular indicators should be based on best available scientific knowledge (Section 4.3). These ecological status classes mark the deviation from a 'natural' reference condition.

68 Further guidance on defining ecological status classes is provided in sections 2.7 and 3.3 of Volume 4.
69 Davies, S.P. and Jackson, S.K. (2006). The biological condition gradient: A descriptive model for interpreting change in aquatic ecosystems: Ecological Applications, v. 16: 1251–1266
70 Langhans, S.D., Lienert, J., Schuwirth, N. and Reichert, P. (2103). How to make river assessments comparable: A demonstration for hydromorphology. Ecological Indicators. 32: 264-275.
71 Davies, S.P., and Jackson, S.K. (2006). The biological condition gradient: A descriptive model for interpreting change in aquatic ecosystems. Ecological Applications., 16: 1251–1266.
72 Kleynhans, C.J. and Louw, M.D. (2007). Module A: EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report: http://www.dwa.gov.za/iwqs/rhp/eco/ecostatus.aspx

Table 3 - Example of an ecological status classification system[73]

A. Natural	B. Largely Natural	C. Moderately Disturbed	D. Largely Disturbed	E. Seriously Disturbed
Changes to ecosystem, ecosystem function and services				
Insignificant changes from natural	Minor changes to ecosystem but no significant loss of ecosystem function/ services	Some loss/change of habitat and biota but basic ecosystem function/services remain	Large loss/change of habitat and biota. Ecosystem function/ services reduced	Extensive loss/ change of habitat and biota. Ecosystem function/ services mostly lost
Percentage deviation from natural ('reference') condition				
0-10	11-20	21-40	41-60	61-100
Sustainability				
Highly sustainable	Highly sustainable	Generally sustainable but requires management	Generally unsustainable. Corrective actions strongly recommended	Unsustainable. Urgent renewal required

However, this natural reference condition can be difficult to determine where human development has had significant impact on ecosystems over long periods of time (see Box 5 and Section 4.3).

SDG indicator 6.6.1 uses the ecological status classes in Table 3. There are three options (in order of preference) for determining the reference condition: (1) natural reference condition; (2) historical reference condition; and (3) SDG baseline reference condition. SDG indicator 6.3.2 is only concerned with two classes of ambient water quality: 'good' or 'not good'. 'Good' is defined as when 80 per cent of all monitoring data from all monitoring stations within the waterbody are in compliance with respective threshold values for each of the parameters measured. These thresholds should reflect a range which do not present a threat to human or ecological health.

Box 5 Ecological Status Classes in the SDGs

4.2 Selecting Indicators[74]

In the context of this volume, an indicator is a measure that can be used to characterize the ecological status of an ecosystem according to status classes.[75] An indicator may reflect the chemical, physical, biological or hydro-geomorphic attributes of an ecological condition. Typically, they are used to provide some insight into the ecological status of an ecosystem in a cost-effective manner, as measuring every variable that may have an impact on ecological status is neither practical nor necessary. Changes in indicator values over time should provide

73 Based on SDG indicator 6.6.1 and adapted from Kleynhans CJ, Louw, MD. (2007). Module A: EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report, South Africa. Note that the percentage deviations from reference are based on the guidelines in SDG indicator 6.6.1, but are likely to vary depending on the ecosystem.
74 Further guidance on indicators is provided in section 4.5 of Volume 4.
75 In different contexts, indicators are sometimes referred to as 'parameters', 'variables' or 'metrics'.

useful insight into changes in ecological status. This step is closely linked to designing the monitoring system, as these indicators will have to be monitored.

Indicators can be combined, following certain aggregation rules, to form an index. An index is useful to condense multiple layers of information (indicators) into a form that is easier to communicate and easier for stakeholders to understand. However, indicator-level information is often required to design targeted management actions to address aspects of poor ecosystem status.

Information gathered in the desktop screening (Section 6) is important to consider in this step.

There are many ecological indicators which have been developed and can be used in different applications.[76,77,78] The challenge lies in selecting the most appropriate indicators based on monitoring objectives, ecosystem type, available resources and capacity. Of course, indicators for the SDGs are predefined and countries report on these as a minimum requirement (Box 6). If a country wishes, and has the capacity to monitor more indicators, then as a guiding principle it is better to select fewer indicators that are meaningful rather than try to measure everything. The goal is to select indicators that can help diagnose the likely cause of observed changes in ecological status and guide management actions. The following are useful considerations in the selection of indicators, though it may not be possible to fulfil all criteria:[79,80]

- Feasibility: adapting an indicator for use in a large or long-term monitoring programme must be feasible and practical given the technical and financial resources available.
- Conceptual relevance and interpretation: the indicator must provide information that is relevant to societal concerns about ecological condition and the services they provide. It must produce results that can be clearly understood and accepted by scientists, policymakers and the public.
- Response variability: it is essential to understand potential reasons for changes in the indicator values, and thus be able to distinguish irrelevant factors from important signals. The indicators should be sensitive to stresses on a system, and able to respond to stress in a predictable manner. They should have a known response to natural disturbances, anthropogenic stresses and changes over time. They should have a low variability in response.
- Indicators should be anticipatory (i.e. signify an imminent change in the ecological system): they should be able to predict changes that can be averted by management actions – i.e. enable the setting of a threshold of potential concern or a trigger value that, if reached, indicates the need for preventative measures.
- Indicators should be integrative: the full suite of indicators should provide a measure of coverage of the key gradients across the ecological systems.[81]

Another tool for indicator selection is to use the SMART criteria, where indicators should be: Specific, Measurable, Achievable, Relevant and Time-bound.[82]

76 Jørgensen, SE, Fu-Liu Xu and Costanza, R. (2010). Handbook of Ecological Indicators for Assessment of Ecosystem Health. Second Edition. CRC Press.
77 Jordan, S, (Ed.) (2010). Estuaries: classification, ecology, and human impacts. Nova Science Publishers.
78 Dept. of Water and Sanitation, South Africa. (2017). Development of Procedures to Operationalise Resource Directed Measures: http://www.dwa.gov.za/rdm/wrcs/default.aspx
79 Adapted from: Jørgensen, SE, Fu-Liu Xu, Marques, JC and Salas, F. (2010). Application of Indicators for the Assessment of Ecosystem Health. In: Handbook of Ecological Indicators for Assessment of Ecosystem Health. Second Edition. Ed. Sven E. Jørgensen Fu-Liu Xu Robert Costanza. CRC Press.
80 Adapted from: Jackson, L E, Kurtz, JC and Fisher, WS, Eds. (2000). Evaluation Guidelines for Ecological Indicators, EPA/620/R-99/005. North Carolina, US Environmental Protection Agency, Office of Research and Development.
81 See also Niemeijer, D. and de Groot, R. 2008. A conceptual framework for selecting environmental indicator sets. Ecological indicators 8, 14–25.
82 Bertule, M., Bjørnsen, P.K., Costanzo, S.D., Escurra, J., Freeman, S., Gallagher, L., Kelsey, R.H. and Vollmer, D. (2017). Using indicators for improved water resources management - guide for basin managers and practitioners. 82 pp. ISBN 978-87-90634-05-6.

As shown in Table 4, indicators can generally be categorized as: physical/chemical; hydro-morphological and biological.

Table 4 - Indicator categories and example indicators.[83]

Category	Sub-category	Indicator examples
Physical / Chemical	Metabolic	Oxygen: dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD); temperature; pH; light penetration (Secchi depth); conductivity/salinity
	Trophic	Nutrients (N, P, NH_4, NOX, soluble P); Chlorophyll-A
	Toxicants	Heavy metals (Cd, Hg, Cr, Cu, etc.); pesticides; other organic pollutants (oil, phenol, polychlorinated biphenyls (PCBs), endocrine disruptors)
Hydro-morphological	Aquatic habitats	Colonizable substrates; substrate condition; velocity and depth variability; sediment deposition; channel flow; habitat diversity; aquatic vegetation; off-channel aquatic habitats
	Riparian habitats	Bank stability; bank vegetative protection
Biological[84]	Fish[85]	Sensitive taxa; relative species richness; size/age structure; disease incidence; alien species; trophic structure; life history traits; reproductive traits
	Invertebrates[86]	Relative taxa richness; size/age structure; life history traits; sensitive taxa; trophic structure; community composition
	Algae	Taxa composition; sensitive taxa; algal biomass
	Macrophytes	Taxa composition; abundance
	Microbial pollutants	E. coli, total coliform count

The selection of indicators will depend on the ecosystem type as well as the types of pressures being exerted on the ecosystem. Examples of types of indicators used for different types of ecosystems are provided below. Often in cases where sufficient ecological information is not available to be able to monitor the preferred indicators, proxy indicators are used to provide an insight into ecosystem integrity.

83 Table adapted from Table 4.4 in Section 4.4.4 of Volume 4. At the time of the development of Volume 4, groundwater was not included, hence this table was developed primarily for surface waters.
84 Although biological indicators are less applicable to groundwater, there are examples of biota in aquifers, such as stygobiota. See: Gibert, J, Dan L. Danielopol, DL & Stanford, J (Eds.). (1994). Groundwater ecology. Academic Press.
85 Klemm, DJ, Stober, QJ &Lazorchak, JM.1994. Fish Field and Laboratory Methods for Evaluating the Biological Integrity of Surface Waters. USEPA, Bioassessment and Ecotoxicology Branch, Cincinnati, Ohio.
86 Dickens, CWS and Graham, PM. 2002. The South African Scoring System (SASS) Version 5 Rapid Bioassessment Method for Rivers. African Journal of Aquatic Science, 27: 1–10.

Table 5 - Typical indicator types for different ecosystem types

Ecosystem Type	Indicator types
Rivers and streams	Indicators may cover water quality; hydrological information; biota, such as fish species populations or assemblages and their health,[87] invertebrates, vertebrates and diatoms; and hydromorphological information such as instream and riparian vegetation that are either important for human consumption, scientific purposes or for indirect water quality assessments. See also discussion of Rapid Biological Assessment (RBA), Australian River Assessment System (AUSRIVAS) and South African Scoring System (SASS5) methods in the subsection on indices following Table 6.
Wetlands	Water quality indicators such as nutrient concentrations, temperature, pH, dissolved oxygen, turbidity, and redox potential. Ecological indicators can include productivity and diversity of phytoplankton and macrophytes, and diversity of macro-invertebrates and birds.[88]
Lakes	Trophic status indicators such as chlorophyll-a, transparency and total phosphorous are often used together with phytoplankton and zooplankton, benthic macro-invertebrate, fish and diatom assemblages as biotic indicators.[89]
Estuaries	Indicators include fish (in terms of the presence and absence of species), the abundance of species, and assessment of fish importance in terms of exploitable species.[90] The Benthic Index of Biotic Integrity (IBI) is also used for estuary health assessment (see indices subsection below).[91] Other biotic indicators include phytoplankton, macrophytes, zooplankton, benthic micro-algae and birds.[92] Abiotic indicators, such as freshwater flows are essential to include as an indicator.[93,94,95,96] Physico-chemical indicators, such as dissolved oxygen, electrical conductivity and pH, are regularly used as pollution indicators.[97]
Groundwater	Aquifer condition is usually assessed using depth to the groundwater table and physico-chemical water quality. Physico-chemical water quality indicators can include electrical conductivity, nitrate and pH. The use of stygobiota as indicators of groundwater conditions may also be relevant.[98,99]

For situations where information and capacity are relatively limited, some indicators can be assessed using relatively straightforward monitoring techniques to provide a rapid ecosystem health check (Table 6). The metabolic indicators provide basic information on water chemistry and light conditions, and are readily assessed as part of any field sampling. The trophic assessment requires easily deployable sampling equipment with basic laboratory analysis, or could be achieved with field kits. The information provides a general assessment of nutrient state in the water bodies, but can be susceptible to error if sampling is very infrequent, especially in rivers. The toxicant measures require more sophisticated or specialized expertise and a laboratory capacity, and are also susceptible to high temporal variability depending on the nature of the water body.

87 Klemm, DJ, Stober, QJ & James M. Lazorchak, JM.1994. Fish Field and Laboratory Methods for Evaluating the Biological Integrity of Surface Waters. USEPA, Bioassessment and Ecotoxicology Branch, Cincinnati, Ohio..
88 S. E. Jørgensen, SE. 2010. Application of Ecological Indicators for the Assessment of Wetland Ecosystem Health. In: Handbook of Ecological Indicators for Assessment of Ecosystem Health. Second Edition. Ed. Sven E. Jørgensen Fu-Liu Xu Robert Costanza. CRC Press.
89 USEPA. 2007. Survey of the Nation's Lakes. Field Operations Manual. EPA 841-B-07-004. U.S. Environmental Protection Agency, Washington, DC
90 Whitfield, A.K. & Elliott, M. (2003). Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future. J.Fish Biol. 64 (Supplement A), 229–250
91 Handbook of Ecological Indicators for Assessment of Ecosystem Health, Second Edition Sven E. Jørgensen, Fu-Liu Xu, and Robert Costanza (2010).
92 Taljaard S, Van Niekerk L, Huizinga P Joubert, W. 2003. Resource Monitoring Procedures for Estuaries for application in the Ecological Reserve Determination and Implementation Process. WRC Report No. 1308/1/03. Water Research Commission, South Africa
93 Adams, J.B., 2014. A review of methods and frameworks used to determine the environmental water requirements of estuaries. Hydrological Sciences Journal, 59:451–465
94 Gippel, C.J., et al., 2009. An asset-based, holistic, environmental flows assessment approach. International Journal of Water Resources Development, 25: 301–330
95 Van Niekerk, L., et al., 2012. An evaluation of the ecological flow requirements of South Africa's estuaries from a hydrodynamic perspective [online]. Pretoria: South Africa. Water Research Commission Report K8/797. South Africa.
96 River flow influence on the fish community of the Tagus estuary (Portugal) Maria Jose´ Costa Æ R. Vasconcelos Æ J. L. Costa Æ H. N. Cabral. Hydrobiologia (2007) 587:113–123
97 Jordan,S.(Ed). 2011. Estuaries : classification, ecology, and human impacts. Nova Science Publishers, Inc
98 Stein, H, Kellermann, C, Schmidt, SI, Brielmann, H, Steube, C, Berkhoff, SE, Fuchs, A, Hahn, HJ, Thulin, B & Christian Griebler, C. 2010. The potential use of fauna and bacteria as ecological indicators for the assessment of groundwater quality. J. Environ. Monit. 12, 242–254.
99 Stein, H, Griebler, C, Berkhoff, S, Matzke, D, Fuchs, A & Hahn, HJ. 2012. Stygoregions – a promising approach to a bioregional classification of groundwater systems. www.nature.com/scientificreports. SCIENTIFIC REPORTS | 2 : 673 | DOI: 10.1038/srep00673

Table 6 – Physico-chemical indicators and monitoring techniques. The metabolic and trophic indicators can be used in situations with relatively low information and capacity to give a preliminary estimate of ecological status.[100]

		Standing waters	**Wetlands**	**Running waters**
Indicator group	**Indicator**	**Approach**		
Metabolic	Oxygen	DO-spot measurement, minimum and yearly fluctuation Event-driven measurements during stress periods, e.g. droughts and high temperatures		
	Temperature	Annual fluctuation Event-driven measurements during stress periods, e.g. droughts		
	pH	Maximum and minimum		
	Light regime	Secchi depth, turbidity or transparency[101]	Transparency (where sufficient surface water is present)	Secchi depths (although sometimes difficult in rivers), turbidity or transparency
	Conductivity/ salinity	Conductivity probe	Conductivity probe (in coastal fringes and delta wetlands only)	Conductivity probe
Trophic	Nutrients N & P	Mean levels of total N and P in agricultural, industrial and urbanized areas		
Toxicants	Heavy metals	Concentrations of heavy metals (Cd, Hg, Cr, Cu, etc.) in agricultural, industrial and urbanized areas		
	Pesticides	Concentrations of specific pesticides in agricultural, industrial and urbanized areas – selection based on local use, environmental fate and toxicity		
	Other organic pollutants	Concentrations of specific organic pollutants like oil, phenol, PCBs in industrial and urbanized areas, including potential endocrine disruptors – selection based on use, environmental fate and toxicity		
	Microbial pollutants	Screening for cyanobacteria, total coliforms, E. Coli and bacteriophages.		

The aggregation of indicators into indices

Selected indicators (e.g. particular fish species or macroinvertebrate taxa (e.g. families)) or indicator groups (e.g. fish, macroinvertebrate, diatoms) can individually provide useful insights into the ecological integrity of a system. They are a useful starting point where capacity may be limited or a rapid assessment is required. In this context, the abundance, frequency of occurrence, or presence or absence of certain biota may be valuable indicators of particular morphological habitat conditions, and perturbations and sensitivity to modified physico-chemical conditions (e.g. pollution).[102,103] The use of biota as ecological integrity indicators is based on empirical information or expert knowledge of the intolerance or tolerance of taxa to particular perturbations.

However, the eventual aim should be an overall assessment of the ecological integrity of the identified ecosystems in order to provide an integrated assessment of the present ecological state. This means that different biological groups (fish, macro-invertebrates, diatoms, vegetation, etc.) can be used in combination with the morphological features of the ecosystem

100 Table adapted from Table 4.9 in Section 4.5.3 of Volume 4. At the time of the development of Volume 4, groundwater was not included, hence this table was developed primarily for surface waters.
101 For a basic description, see http://watermonitoring.uwex.edu/pdf/level1/FactSeries-Turbidity.pdf
102 Whitfield, AK & Elliot, M. 2002. Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future. Journal of Fish Biology. 61 (Supplement A): 229–250
103 Fausch, KD, Lyons, J, Karr, JR & Angermeier, PL. 1990. Fish communities as indicators of environmental degradation. American Fisheries Society Symposium 8:123-144

and abiotic driver modification to construct an integrated index value that can be related to the ecological status classes.[104,105] A range of methods for the creation of indices exist, some of which are described in the following paragraphs, generally starting with simpler approaches and progressing to more complex approaches that lead to a higher confidence in results.[106] A consideration of the overall method to assess ecological state, or creation of an index, helps to guide the selection of indicators.

A relatively simple and rapid approach, which can be used in desktop screening, is the Present Ecological State (PES), and related Ecological Importance and Sensitivity (PESEIS) approach.[107] The PES component of the PESEIS uses indicators of modification as surrogates for habitat and ecological integrity. It relies on local expert knowledge and is typically semi-quantitative, depending on the level of information available. The level of confidence in the results can be increased when 'ground-truthing' is conducted, together with Earth Observation information such as Google Earth images. Six metrics are used to assess the instream and riparian conditions and provide an assessment of the PES according to ratings for the categories:

- Instream habitat continuity modification activities
- Riparian-wetland zone continuity modification activities
- Potential instream habitat modification activities
- Riparian-wetland zone modification activities
- Potential flow modification activities
- Potential physico-chemical modification activities

Ecological Importance and Sensitivity (the IES part of PESEIS) is assessed according to a range of metrics that, among others, use indicators of the sensitivity of biophysical entities to potential modifications. Again, this is a very broad desktop-level assessment that could be conducted by local expert ecologists.

For rivers, the Index of Habitat Integrity (IHI) is another example of a low-cost approach that can be used to monitor habitats at a broad reach scale,[108] and also at a more detailed level (e.g. site assessment).[109] In essence, this type of assessment uses an evaluation of modification to system drivers, and instream and riparian habitat features as a surrogate for the presence of biota. This kind of assessment involves an analysis of river reach scale information, remote sensing (earth observation) such as Google Earth images and low-level aerial surveys (including drones), and site-based (ground-truthed) observations and assessments. Local expert knowledge often makes a substantial contribution to this kind of evaluation. A similar broad-based assessment of wetlands can be done with the Wetland IHI.[110] Where water quality and flow information are available, these should be used.

For reservoirs, a quick and relatively simple condition assessment method is the Index of

104 Kleynhans CJ, Louw MD. 2007. Module A: EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. http://www.dwa.gov.za/iwqs/rhp/eco/ecostatus.aspx
105 Davies, S.P., and Jackson, S.K., 2006, The biological condition gradient: A descriptive model for interpreting change in aquatic ecosystems. Ecological Applications. 16: 1251–1266.
106 For a review of international methods available for assessing ecological condition, see http://www.wrc.org.za/Knowledge%20Hub%20Documents/Research%20Reports/TT%20608-14.pdf
107 http://www.dwa.gov.za/iwqs/rhp/eco/peseismodel.aspx
108 Kleynhans, CJ. 1996. A qualitative procedure for the assessment of the habitat integrity status of the Luvuvhu river (Limpopo system, South Africa). Journal of Aquatic Ecosystem Health 5: 41-54. http://www.dwa.gov.za/iwqs/rhp/eco/ecostatus.aspx
109 Kleynhans CJ, Louw MD & Graham M, 2008. Module G: EcoClassification and EcoStatus determination in River EcoClassification: Index of Habitat Integrity (Section 1, Technical manual) Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT 377-08. South Africa. http://www.dwa.gov.za/iwqs/rhp/eco/ecostatus.aspx
110 DWAF. 2007. Manual for the assessment of a Wetland Index of Habitat Integrity for South African floodplain and channelled valley bottom wetland types. M. Rountree (ed).

Reservoir Habitat Impairment. Expert knowledge is employed to rate impairments such as suspended sediments or inorganic turbidity, sedimentation, shoreline erosion, excessive nutrients, point-source pollution, contaminants, oxygen or temperature stratification, miss-timed water level fluctuations, insufficient water storage, excessive aquatic macrophytes, lack of aquatic macrophytes, lack or loss of woody debris, disconnectivity with backwaters, and invasive plant species. Ratings are analysed using a Likert scaling system.[111,112]

Slightly more advanced approaches to broad-scale assessments and early detection of deterioration in rivers include Rapid Biological Assessment (RBA) methods. The advantage of RBA methods is that they can be carried out at relatively low cost at a large number of sites or over a large geographical area. The Australian River Assessment System (AUSRIVAS) includes an RBA approach for stream macro-invertebrates.[113,114] Similarly, the South African Scoring System (SASS5) provides a rapid assessment of water quality conditions in rivers.[115] RIVPACS is a similar approach that uses macro-invertebrate composition from a variety of reference sites against which test sites are compared.[116] The European Union Water Framework Directive (WDF) uses RIVPACS-type models as well as the WFD System-A and System-B models.[117]

Lake condition is often assessed based on direct measurement methods (DMM). The DMM approach includes identification of key indicators, direct measurement or indirect calculation of selected indicators and assessment of system status on the basis of the indicator values. Key indicators can include phytoplankton, zooplankton and aspects of chlorophyll-a.[118]

The Ecosystem Health Index Methodology (EHIM) for lakes assesses ecosystem health on a scale from 0 (worst condition) to 100 (best possible condition). One of the five steps followed in the EHIM is the selection of basic (phytoplankton biomass) and additional indicators (zooplankton biomass and the ratio of zooplankton biomass to phytoplankton biomass). This approach is considered as relatively simple to apply as a planning tool, and can be widely used for the quantitative assessment and comparison of lake condition for a single lake and a series of different lakes.[119]

Multiple attribute (multi-metric) approaches are also used to assess human impact on aquatic organisms – for example, the fish Index of Biotic Integrity[120,121](IBI) and variations based on it,[122] which include pollution tolerance, diversity, and ecological function metrics.[123] Pathological fish abnormalities are also considered as important indicators of lake condition.[124]

111 https://en.wikipedia.org/wiki/Likert_scale
112 Miranda, LE & Hunt, KM. 2011. An index of reservoir habitat impairment. Environ. Monit. Assess, 172:225–234
113 See Section 3.5.3 of Volume 4.
114 Chessman, BC. 1995. Rapid assessment of rivers using macroinvertebrates: A procedure based on habitat-specific sampling, family level identification and a biotic index. Austral Ecology, 20: 122–129.
115 Dickens, CWS & Graham, PM. 2002. The South African Scoring System (SASS) Version 5 Rapid Bioassessment Method for Rivers. African Journal of Aquatic Science, 27: 1–10.
116 Assessing The Biological Quality Of Fresh Waters: Rivpacs And Other Techniques. 1997. Ed: Wright, J& Sutcliffe, D, Furse, MT. Freshwater Biological Association, Ambleside, Cumbria, UK.
117 Davy-Bowker, J, Clarke, RT, Richard K. Johnson, RK, Kokes, J, Murphy, JF & Zahra'dkova´, S. 2006. A comparison of the European Water Framework Directive physical typology and RIVPACS-type models as alternative methods of establishing reference conditions for benthic macroinvertebrates. Hydrobiologia, 566:91–105..
118 Fu-Liu Xu et al. 2001. Lake Ecosystem Health Assessment: Indicators and Methods. Wat. Res. Vol. 35, No. 13, pp. 3157–3167
119 Fu-Liu Xu et al. 2005. An ecosystem health index methodology (EHIM) for lake ecosystem health assessment. Ecological Modelling 188: 327–339
120 Karr, JR. 1981. Assessment of biotic integrity using fish communities. Fisheries 6: 21–27
121 Fausch, KD, Lyons, J, Karr, JR & Angermeier, PL. 1990. Fish communities as indicators of environmental degradation. American Fisheries Society Symposium 8:123-144.
122 Kleynhans, CJ. 2007. Module D: Fish Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2) Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT330/08
123 Jørgensen, SE, Fu-Liu Xu & Costanza, R (Eds.). 2010. Handbook of Ecological Indicators for Assessment of Ecosystem Health. Second Edition. CRC Press.
124 USEPA. Lake and Reservoir Bioassessment and Biocriteria: Technical Guidance Document. EPA 841-B-98-007

4.3 Setting Threshold Values for Ecological Status Classes[125]

The purpose of this step is to set threshold values for the selected indicators, to be able to assign an ecosystem to ecological status categories.

There are two main approaches to setting threshold values:

1. Based on monitored data: This is the more robust method. By using data from similar ecosystems that are in a natural or near-natural condition, threshold values can be derived for 'higher' ecological classes, and these can be used or modified for ecologically comparable (e.g. in terms of ecosystem type and ecoregion) but data poor ecosystems (Box 7).
2. Based on guideline values from other jurisdictions: Where data are inadequate for setting threshold values, it is possible to use guideline values from jurisdictions with similar ecosystem and ecoregion types. However, as ecosystems are so variable and dependent on a range of variables, a cautionary approach should be followed when using guideline values.

Countries are likely to adopt a combination of both, depending on the availability of data for indicators, and the range of ecological statuses displayed by ecosystems. With either method, it is preferable to extrapolate information from ecosystems that are most similar.

The indicator methodology for SDG 6.3.2 describes in detail how to determine thresholds for 'good' ambient water quality based on monitored data for particular indicators.

Box 7 Setting threshold values in SDG 6.3.2.

For biological indicators, it is recommended to use information from ecosystems with similar species and taxa belonging to groups with similar environmental requirements and life history styles (i.e. similar biological guilds). Models and relatively simple methods exist to predict the presence of biota if sufficient data on abiotic indicators at sites where species are known to occur are available.[126,127,128,129,130,131] Setting thresholds for presence of fish species (such as catch per effort for certain species) and invertebrate taxa may be derived based on suitable historical information from the same or a comparable system.[132,133,134]

Table 7 provides a range of thresholds for certain indicators based on internationally and nationally established criteria, and standards designed to both protect intact freshwater

125 Further guidance on setting threshold values for indicators is provided in section 4.5 of Volume 4.
126 Smith, MJ, Silander,JA & Merow, C. 2013. A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. Ecography 36: 1058–1069.
127 Mouton, A., 2008. A critical analysis of performance criteria for the evaluation and optimisation of fuzzy models for species distribution. PhD thesis, Ghent University, Gent, Belgium
128 Olden, JD & Jackson, DA. 2002. A comparison of statistical approaches for modelling fish species distributions Freshwater Biology, 47: 1976–1995
129 Quist, MC, Rahel, FJ & Hubert, WA. 2005. Hierarchical faunal filters: an approach to assessing effects of habitat and non-native species on native fishes Ecology of Freshwater Fish 2005: 14: 24–39
130 Chessman, BC. 2006. Prediction of riverine fish assemblages through the concept of environmental filters. Marine and Freshwater Research, 57: 601–609.
131 Hawkins, CP, Norris, RH, Gerritsen, J, Hughes, RM Susan K. Jackson,SK, Johnson, RK & Stevenson, RJ. 2000. Evaluation of the use of landscape classifications for the prediction of freshwater biota: synthesis and recommendations J. N. Am. Benthol. Soc.19:541–556.
132 Department of Water Affairs, 2011: Procedures to Develop and Implement Resource Quality Objectives. Department of Water Affairs, Pretoria, South Africa. Co-ordinated by: Institute of Natural Resources.
133 Chessman, BC & Royal, MJ.2004. Bioassessment without reference sites: use of environmental filters predict natural assemblages of river macroinvertebrates. J.N. Am. Benthol. Soc.23:599-615
134 Cyterski and Barber. 2006. Identification and Prediction of Fish Assemblages in Streams of the Mid-Atlantic Highlands, USA

ecosystems and to characterize severe ecosystem degradation. These values should be considered as guideline values only and must be used with caution in national applications. However, they are useful where no local benchmarks exist. The values are derived from an extensive survey of known guideline values and are close to the median values from countries and organizations such as Australia/New Zealand, Canada, China, the EU, Japan, South Africa, the United Nations Economic Commission for Europe and the US.

Table 7 - Possible physico-chemical thresholds for freshwater ecosystems. Annual average total concentrations, unless indicated otherwise[135]

Indicators	Class A - Natural[136]	Class E – Seriously Disturbed
Dissolved Oxygen Saturation (%)	80 - 120	< 30 or > 150
Dissolved Oxygen Concentration (mg/l)	7.3 - 10.9 2	<3 or > 13.6 2,3
(optional) BOD_5 (mg/l)	-	>10
Total Phosphorus (TP) (μg/l) - lakes and reservoirs - rivers and streams	 < 10 < 20	 >125 >190
Total Nitrogen (TN) (μg/l) - lakes and reservoirs - rivers and streams	 < 500 < 700	> 2500 > 2500
Chlorophyll-a (μg/l) - lakes and reservoirs - rivers and streams	 < 3.0 < 5.0	 > 165 > 125
pH	6.5 – 9.0	< 5
Temperature	No deviation from background value or reference systems or optimum temperature ranges of relevant species	Large deviations from background value or the thermal tolerance range for characteristic species
Un-ionized Ammonia (μg NH_3/l)	15[5]	100[5]
Aluminium (μg/l) pH <6.5 pH >6.5	 5 10	 - 100
Arsenic (μg/l)	10	150
Cadmium (μg/l) [4]	0.08	1.0
Chromium (μg/l) [4] Cr III Cr VI	 10 1	 75 40
Copper (μg/l) [4]	1	2.5
Lead (μg/l) [4]	2	5
Mercury (μg/l) [4]	0.05	1.0
Nickel (μg/l)[4]	20	50
Zinc (μg/l) [4]	8	50

1 Natural sources and geographical conditions may cause natural background values that differ from the benchmarks for high integrity. Instead of these benchmark values natural background concentrations may be used for setting criteria for high integrity.
2 Dissolved oxygen concentration varies depending on temperature, pressure and salinity; benchmarks are for freshwater at sea level (760 mm Hg) and 20ºC based on the DO%.
3 Daily average.
4 Applicable for waters with low hardness (< 60 mg/l $CaCO_3$). In case of higher hardness, the benchmark values may be somewhat higher.
5 Corresponding total ammonia (NH_3 + NH_4^+) concentration depend on pH and temperature. At pH 7.5 and 20ºC the benchmarks for total ammonia- N are 1000 μg/l and 6641 μg/l respectively.

135 This table is from section 4.5.3 of Volume 4. The rationale behind the values is described in that section and in Annex 2 of Volume 4. Groundwater assessments were not included in the development of Volume 4, and hence the values in this table were derived for surface waters. Nonetheless, for groundwater where there is a significant interaction with surface water, the threshold values for many of the indicators would still be relevant.
136 Classes refer to the example classes of ecological status as shown in Table 3 in Section 4.1

4.4 Setting Targets for Ecosystem Status[137]

In this context, 'targets' refer to management targets for the ecological status of ecosystems. Setting ecosystem status targets involves the consideration of the desired ecological status class for each ecosystem – for example, 'largely natural' or 'moderately disturbed' (see Table 3 in Section 4.1).[138] This can be referred to as the Target Ecological Class (TEC),[139] and is ultimately decided upon through a sociopolitical process, closely linked to the vision and objectives (Initiation Phase).[140] As such, the adequate involvement of stakeholders is a prerequisite. It is important that stakeholders be made aware of the consequences of different development scenarios through the involvement of ecologists and other experts. Targets should be set in the context of sustainable development, with consideration for national and international (see Box 9) sustainable development and biodiversity protection objectives and targets.

For some ecosystems, it may be possible to set high targets – for example, to achieve natural or largely natural conditions (as described in Table 3, section 4.1). This is sometimes referred to as 'Least Disturbed Condition'. However, this may not always be feasible, especially in human-dominated landscapes that are the product of interactions between societies and ecosystems over many thousands of years. Some freshwater ecosystems (e.g. many lowland rivers) may already be disturbed by centuries of human activity. Thus, the presence of human activities in the landscape, and their impact on ecosystems, needs to be acknowledged in the setting of targets. This approach is sometimes referred to as 'Best Attainable Condition' (BAC), defined as the condition that could be achieved by implementing best management practices.[142] BAC is not to be confused with management objectives, which involve trade-offs between ecosystem health and the costs of management interventions to protect or restore them. Rather, BAC acknowledges the presence of humans in the landscape and considers what is technically possible. For example, if point-source pollution is eliminated, and diffuse pollution is reduced by best practices in urban and rural catchment management, degraded habitats can be rehabilitated. In most settings, such kinds of action should enable a high level of ecological remediation.[143]

An adaptive management approach is also applicable to target setting. It can be useful to set short-term, medium-term and long-term targets, and to periodically review the progress towards these targets – and potentially review and revise the targets themselves (see Box 8).[144]

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137 Further guidance on setting targets for ecosystem status is provided in sections 2.7 and 4.1.6 of Volume 4.
138 Kleynhans CJ, Louw MD. 2007. Module A: EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. http://www.dwa.gov.za/iwqs/rhp/eco/ecostatus.aspx
139 DWS, South Africa. 2016. Main Report. http://www.dwa.gov.za/rdm/wrcs/default.aspx
140 See Section 2.1 of this Volume and Section 3.1.2 of Volume 1.
141 DWS, South Africa. 2016. Development of Procedures to Operationalise Resource Directed Measures. Stakeholder involvement and communication tool analysis and standardisation Report. Prepared by Anelle Lötter for Rivers for Africa eFlows Consulting (Pty) Ltd. Report no RDM/WE/00/CON/ORDM/1116. http://www.dwa.gov.za/rdm/wrcs/default.aspx
142 Stoddard J.L., Larsen D.P., Hawkins C.P., Johnson R.K., Norris R.H. (2006). Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological Applications, 16, 1267–1276.
143 See Section 2.7, Volume 4.
144 For further guidance on adaptive management, see Sections 2.9.1 and 4.8.1 of Volume 4.

In 1983, a management strategy for Lake Balaton in Hungary set the following targets for water quality, based on historic records and stakeholder memories:

- By 1990: prevent further deterioration
- By 1995-2000: gradual improvement
- By 2005-2010: restore the water quality of the early 1960s

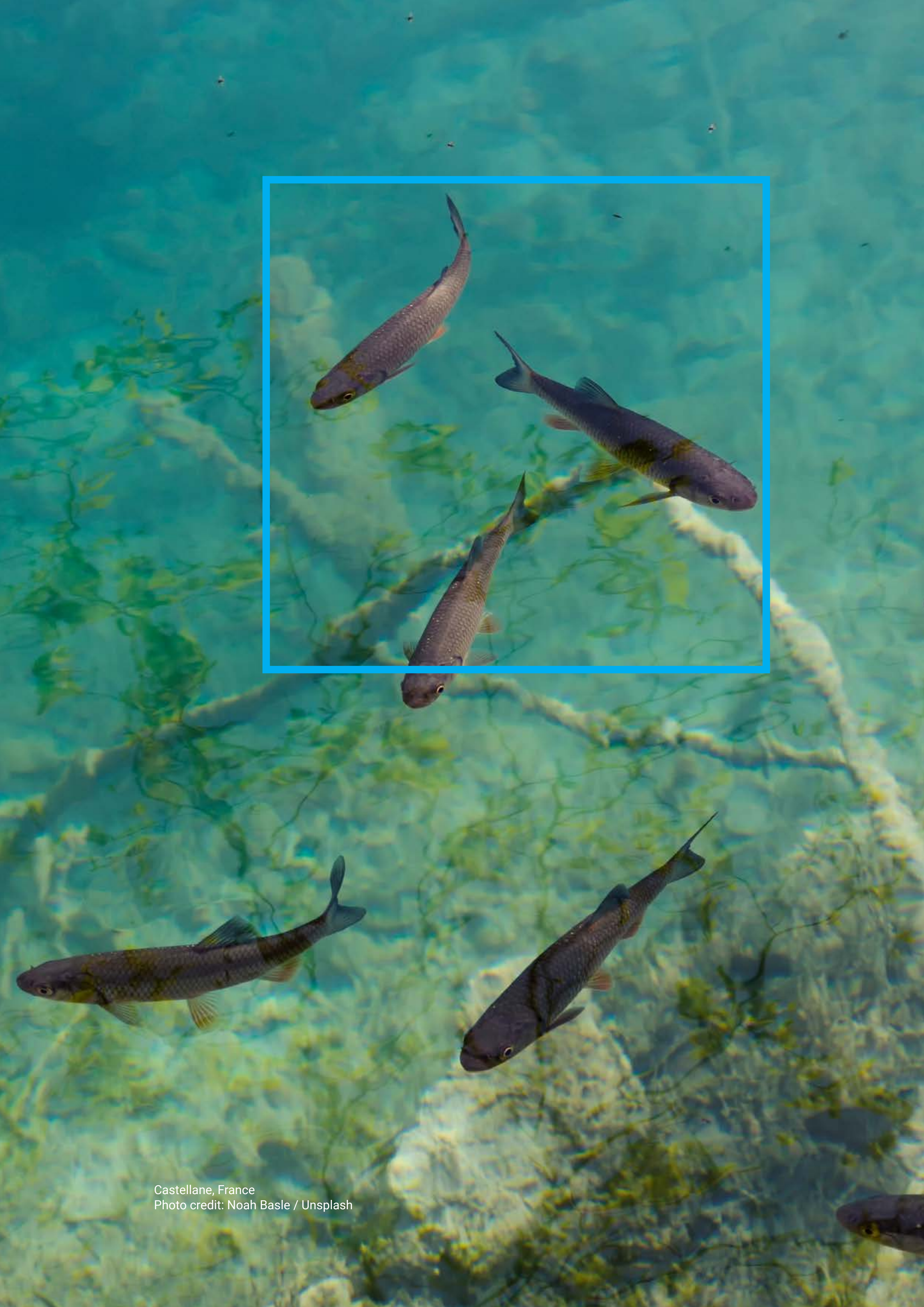
Each target had qualifying criteria. For more information, see Volume 3: Case Studies.

Box 8 – Setting short-, medium-, and long-term management targets

Target 6.3 is "By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally." Only the part which covers halving the proportion of untreated wastewater is globally quantifiable. The majority of the target requires countries to set their own aspirations for improving water quality.

Target 6.6, which is aligned with Aichi Biodiversity Target 5, is "By 2020 protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes." This is clearly an ambitious target, and it is up to countries to develop a realistic plan to work towards it.

Box 9 Targets in the SDGs.



Castellane, France
Photo credit: Noah Basle / Unsplash

5 Assessing Capacity (Initiation Phase)

PART B: Further Information on Capacity Assessment, Identification and Desktop Screening, and Monitoring

Initiation Phase

- Assess Capacity
- Set Vision & Objectives
- Design Classification Frameworks

For an overview of the phases and steps in the Framework, see Section 2. Annex 1 provides additional information on the sub-steps.

In order to design or revise activities to sustainably manage ecosystems, it is important to have an understanding of the country's capacity to do so. Thus, a systematic capacity assessment is recommended. The intention of this step is to undertake a broad-level capacity assessment at the national level. It is linked to the desktop screening step in the Identification Phase, which involves a more detailed screening of the existence and adequacy of data availability at the basin level. Thus, information gathered in this step may (depending on the level of detail) feed into information gathered in the Identification Phase.

> Capacity assessment is a key early step in SDG 6.3.2, which advises that a formal assessment of existing water quality monitoring activity should be performed nationally.

Box 10 – Capacity assessment in SDG 6.3.2

There are numerous capacity assessment methodologies and frameworks, and it is up to each country to design a capacity assessment that is suitable for the national context.[145,146,147] One option is to structure a capacity assessment around the four core components of the governance framework described in Section 4 of Volume 1 – which are also commonly referred to in Integrated Water Resources Management, as measured by SDG indicator 6.5.1.[148] These components may be considered at different levels as appropriate to each country: national,

145 GEF Global Support Programme 2005. Resource Kit for National Capacity Self-Assessment. United Nations Development Programme. Accessed Oct 2017 https://www.unpei.org/sites/default/files/PDF/institutioncapacity/National-Capacity-Self-Assessment-Resource-Kit.pdf

146 UNDP 2005. A Brief Review of 20 Tools to Assess Capacity. UNDP Resource Catalogue. https://www.unpei.org/sites/default/files/PDF/institutioncapacity/Brief-Review-20-Tools-to-Assess.pdf

147 UNDP 2008. Capacity Assessment Practice Note. http://content-ext.undp.org/aplaws_publications/1448681/Capacity%20Assessment%20Practice%20Note.pdf

148 http://iwrmdataportal.unepdhi.org/iwrmmonitoring.html

subnational, local, and even transboundary (in cases where ecosystems, or the basins in which they are located, are shared by two or more countries).

1. Enabling Environment: the extent to which government policies, laws and plans contain provisions for the sustainable management of ecosystems. These need not be limited to the environmental sector or associated ministry, but may be related to other sectors which depend on, or may impact, freshwater ecosystems. This element is also linked to the agreed vision for freshwater ecosystems, as addressed in the Initiation Phase.
2. Institutions and Participation: this refers to both the institutional and human capacity to sustainably manage ecosystems.[149] In regards to institutional capacity, the following questions could be used for guidance: Which government and non-governmental organizations have responsibility for sustainably managing ecosystems? What is their capacity to implement plans and programmes? Do they have available financial resources? How well do they implement their plans? What is the degree of collaboration between various agencies – across sectors, including public and private ('horizontal integration'), and at different levels ('vertical integration')? In regards to human capacity: What is the status of tertiary-level education and on-the-job training, either in general and/or in the field of freshwater ecosystem management? Are there any issues related to staff retention, or 'institutional memory' that could affect consistency in programmes over time? An in-depth institutional capacity assessment is likely to require significant time and resources, but if capacity is relatively low, a rapid assessment would still be a useful exercise.
3. Management instruments: these include monitoring systems covering a range of factors relevant to freshwater ecosystems, including water availability and use, the extent of lakes and wetlands, and biological monitoring. These are elaborated on in the 'Design classification frameworks' step. The capacity assessment should consider the geographical coverage of monitoring, as well as the relevance, quality, frequency and cost effectiveness of data collected. Activities may extend beyond the ministry or water authority that holds overall responsibility for monitoring water, to include institutions such as universities or private sector organizations. Monitoring programmes should be designed and implemented in conjunction with guidelines for water quality and quantity for other uses. Many countries will have water quality guidelines for drinking water, irrigation and bathing, for example. These should be taken into consideration when developing water quality guidelines for ecosystems (see Section 4.3). Management instruments can also include: programmes for sustainable management of ecosystems such as developing sustainable livelihoods from ecosystems; educational programmes to reduce pollution and other impacts; programmes for dam management to ensure environmental flows; and financial incentives for reducing water use or pollution.
4. Financing: refers to the financial resources available, including central government budget allocations, and other sources such as fees and tariffs levied on water users and polluter fees. In addition to these ongoing revenue streams, grants may be available – for example, through donor funding, international organizations, charities or philanthropic funds.[150]

The level of detail in a capacity assessment depends on the national context. At the most basic level, it is important to have an overview of the enabling environment, institutions, management instruments and financing arrangements that relate to the sustainable management of freshwater ecosystems. At a more advanced level, it is useful to assess whether the arrangements in place are adequate. To establish this, it would be useful to determine what is required for each of the elements. For example, at the basic level, one may be able to identify a relevant law, and at the more advanced level, one can try to determine what the law needs to be able to achieve, and whether or not it is adequate for that purpose. Ideally, these minimum requirements should be identified and stipulated in the capacity assessment report. To some extent, the minimum requirements depend on the agreed

149 See Section 4.8.2 of Volume 4 for more information on capacity issues relating to professional and institutional competence.
150 See Section 4.9 of Volume 4 for more information on financing issues.

vision for freshwater ecosystems, as well as on the more detailed screening undertaken in the Identification Phase. Therefore, the initial capacity assessment is only based on current priorities, and existing information on ecosystems and pressures. The capacity assessment can be refined as information is gathered through subsequent steps.

Understanding the level of capacity within a country and identifying capacity gaps, will help to determine what is practically achievable within a country, as it influences subsequent steps in this Framework and informs the design of activities to sustainably manage freshwater ecosystems.

There is likely to be significant variation in capacity between countries and across the different elements assessed. For example, some countries may have an active monitoring network, but it may not be supported by policy or legal frameworks. Or they may have strong policy, but lack adequate funding to implement the policy. Understanding the level of capacity for a particular element can also facilitate learning between countries.
For countries with relatively low levels of capacity across most of the elements of sustainable management of ecosystems, there are some cost-effective steps that can be undertaken to gain a rough idea of the state of ecosystems and pressures on them in a country (see recommendation at the end of Section 2).

Private Sector and Civil Society Engagement:

Assessing the extent to which the private sector and civil society are effectively engaged in areas related to sustainable management of freshwater ecosystems should also be included in a capacity assessment. There are a number of opportunities where engaging with both the private sector and civil society are recommended. For the private sector, these include, but are not limited to:

- Working with industries producing wastewater to minimize impacts where possible and ensure compliance with regulatory standards
- Working with wastewater treatment utilities, where private or semi-private, to reduce negative impacts on freshwater ecosystems, and increase benefits, such as a steady supply of water
- Encouraging the use of nature-based solutions, such as constructed wetlands for wastewater treatment, which mimic natural ecosystems and provide many of the same services
- Working with the agricultural sector, including agribusiness, to reduce diffuse and point-source wastewater pollution, and to increase the use of nature-based pollution prevention measures such as buffer strips
- Working with private developers to minimize development impacts on ecosystems and their services, and exploring opportunities to harness the value of ecosystem services
- Working across the private sector to help it understand the benefits derived from ecosystems, and the risks posed from disturbed ecosystems
- For civil society, there are a large number of non-governmental organizations (NGOs) and platforms that are engaged in ecosystem monitoring, protection and restoration. These can aid in freshwater ecosystem management in a number of ways:
- NGOs and citizen science platforms can help in gathering data and information on the state of freshwater ecosystems and flagging areas or systems where there is a problem with pollution and ecosystem degradation, or tracking their health through biological monitoring (bird counts, frog counts, etc.).
- NGOs and citizen science platforms can raise awareness around the value of enjoying ecosystem services for recreation or biodiversity and the importance of the protection and restoration of freshwater ecosystems.[151]

151 http://www.accaglobal.com/content/dam/acca/global/PDF-technical/environmental-publications/natural-capital.pdf, http://www.ifc.org/wps/wcm/connect/3aebf50041c11f8383ba8700caa2aa08/IFC_GoodPracticeHandbook_CumulativeImpactAssessment.pdf?MOD=AJPERES, https://www.bsr.org/reports/BSR_Private_Engagement_With_Ecosystem_Services_2014.pdf

Goðaland, Iceland
Photo credit: Brian Botos_Skógafoss/ Unsplash

6 Identification Phase: Identifying Ecosystems and Classifying by Type, Setting Basin Context, and Desktop Screening and Assessment

The Identification Phase involves the initial identification of freshwater ecosystems within a country, and a determination of the basin context in which they exist. Once the ecosystems have been identified, they can be screened to determine the main stresses and risks, as well as which are likely to be most 'at risk', and which are likely to be least 'at risk' or in a near-natural condition.

Identification Phase

- Identify Ecosystems & Classify by Type
- Set Basin Context
- Desktop Screening & Assessment

The steps in this Phase may be particularly important for those countries with relatively low capacity for monitoring and assessing ecosystems in detail. A basic inventory of ecosystems and hydrological basins in a country is the basis for all future monitoring, assessment and management activities.

Identify Ecosystems and Classify by Type

The identification and classification of ecosystems should ideally use the classification system designed in the Initiation Phase so that the data can be organized in a structured manner. However, even if classification systems have not been fully developed, a basic inventory of ecosystems can still be a useful starting point.

Groundwater may be the most challenging ecosystem type to identify. Often boundaries and catchments can be hard to delineate, and many aquifers are transboundary in nature. National information on groundwater may be cross-referenced with regional and global studies.[152]

152 Global transboundary aquifers: https://www.un-igrac.org/resource/transboundary-aquifers-world-map-2015;
African transboundary aquifers: https://wle.cgiar.org/content/transboundary-aquifer-map-africa;
World Karst Aquifer Mapping Project: https://link.springer.com/article/10.1007%2Fs10040-016-1519-3

Set Basin Context[153]

Setting the basin context depends on the type of ecosystem and the level of detail used in the classification system. For example, an ecosystem broadly classified as a river will be located within the main river basin. In more detailed classification systems (e.g. upper or lowland) each river reach will be located within a sub-basin (see Figure 4). Lakes and wetlands will typically be part of a main river basin, but will be specifically located within their own sub-basin. Using the example in Figure 4, if a wetland or lake is located near the downstream part of sub-basin 9, then effectively its basin is sub-basin 9. However, if it is located in sub-basin 7, then it could be impacted by upstream activities (e.g. pollution) in sub-basins 9, 8 and 7; these three sub-basins may be considered the basin for the wetland or lake.

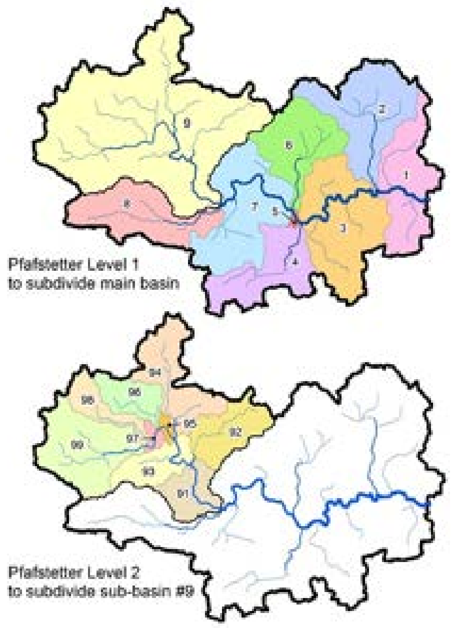


Figure 4 - Example of river basin divided into different levels of sub-basin (from HydroBASINS)

In this step, it is important to determine the connections between the freshwater ecosystems (as identified in the previous step) within each basin.

Where basin delineations do not exist, or there is insufficient time, resources or capacity to delineate basins, global data sets are available, derived from satellite data. One of the most comprehensive data sets is HydroBASINS.[154]

At the most basic level, the ecosystems and their basins can be listed in a document or database. The next step would be to progressively map this information in a Geographic Information System (GIS). As capacity permits, additional 'layers' of information can be added to the GIS database, such as land-use types (e.g. irrigated agriculture, protected areas, pasture for livestock), the location of urban centres (starting with the highest populations, and including smaller population centres as data allows), and the location of major infrastructure (such as dams, electricity generation plants and transport links). This information is useful to understand the likely pressures on ecosystems at the basin level (see next step).

Desktop Screening and Assessment[155]

The aim of this step is to analyse available data and information, and on this basis, compile the first assessment of the status of freshwater ecosystems. This is particularly useful for countries that do not already have extensive data and information on the majority of freshwater ecosystems, and comprehensive monitoring and reporting programmes in place (as addressed in the Assessment Phase). In such cases, this step can provide a useful basic assessment of freshwater ecosystems in a relatively short time (e.g. less than 6 months, depending on the size of the country), while designing a comprehensive monitoring system and collecting data may take several years, depending on the scope and scale of the monitoring and assessment.

153 Further guidance on setting the basin context is provided in section 4.3 of Volume 4.
154 http://www.hydrosheds.org/page/hydrobasins
155 Further guidance on desktop screening is provided in sections 2.4 and 4.4 of Volume 4.

This step need not be limited to a desktop study, but may also involve inputs from experts and stakeholders as appropriate. Individuals and groups could have valuable information (mainly qualitative) that may not be written down and publicly accessible. Importantly, this step should make use of existing data and information, and does not require additional data collection or monitoring. This step has three parts:

- Assess data availability by basin
- Screen for pressures
- Estimate the ecological status of each ecosystem

The first part builds on the capacity assessment in the Initiation Phase (Section 5), and is a more detailed assessment of the existence and adequacy of data at the basin level. There are two main objectives to this: (a) to identify all current data and information available on each ecosystem at the basin level that can be used to screen for pressures and estimate ecological status; and (b) to assess current capacity and gaps, which can be used to design or refine monitoring systems (see Assessment Phase). Data and information may include: government reports; Environmental and Social Impact Assessments (EIAs and SIAs) or similar; research; and community and indigenous knowledge.

Some typical pressures that may be identified during the screening process are given in Table 8.

Table 8 - Main categories of pressures on freshwater ecosystems with examples[156]

Category	Types	
Loss or modification of habitat	Expansion of agricultural or urban areas, river training, sedimentation, dredging, mining	
Water infrastructure	Infrastructure which either affects the natural flow of water downstream, upstream or across floodplains, such as dams, dykes, weirs, barrages and canals	
Flow alteration	Water withdrawals from various sectors, reservoir operations, inter-basin transfers	
Water pollution	Chemical	Agricultural (e.g. pesticides, fertilizers), industrial (e.g. heavy metals, persistent organic pollutants – POPs), municipal (wastewater)
	Biological	Invasive alien species
	Thermal	Cooling water discharge (warm water), reservoir discharges (cool water)
Overexploitation	Overfishing, overhunting	

The desktop screening is the first attempt to estimate the ecological state of each ecosystem based on available information identified through this Identification Phase. The main objective is to identify those ecosystems which are: (a) likely to be in good ecological condition, or those that may be of particular environmental or social significance (from a national or international perspective – see below); or (b) likely to be highly degraded or with significant pressures that put them at risk of degradation in the future. In other words, the desktop screening should identify those ecosystems at either end of the spectrum. This screening process may be undertaken at various levels within a country. International considerations may also need to be taken into account, including where freshwater ecosystems or their basins cross international borders, or in relation to international agreements and records, such as:

156 Table adapted from Table 4.3 in Section 4.4.2 of Volume 4, which also suggests indicators to monitor these pressures. At the time of the development of Volume 4, groundwater was not included, hence this table was developed primarily for surface waters, though some pressures still apply to groundwater.

- The Ramsar Convention on Wetlands, which maintains a 'List of Wetlands of International Importance'
- The Montreux Record, which is a register of wetland sites on the List of Wetlands of International Importance where changes in ecological character have occurred, are occurring or are likely to occur as a result of technological developments, pollution or other human interference
- The UNESCO Wold Heritage List[157] and the World Heritage in Danger List[158], particularly within the 'natural' or 'mixed' categories
- Key Biodiversity Areas (KBAs),[159] the IUCN Red List of Ecosystems[160] and the IUCN Green[161]

List of Protected and Conserved Areas

If freshwater ecosystems are identified on any of these lists, then it is likely that there will be additional information on them, and that initiatives may already exist to monitor, protect and restore them.

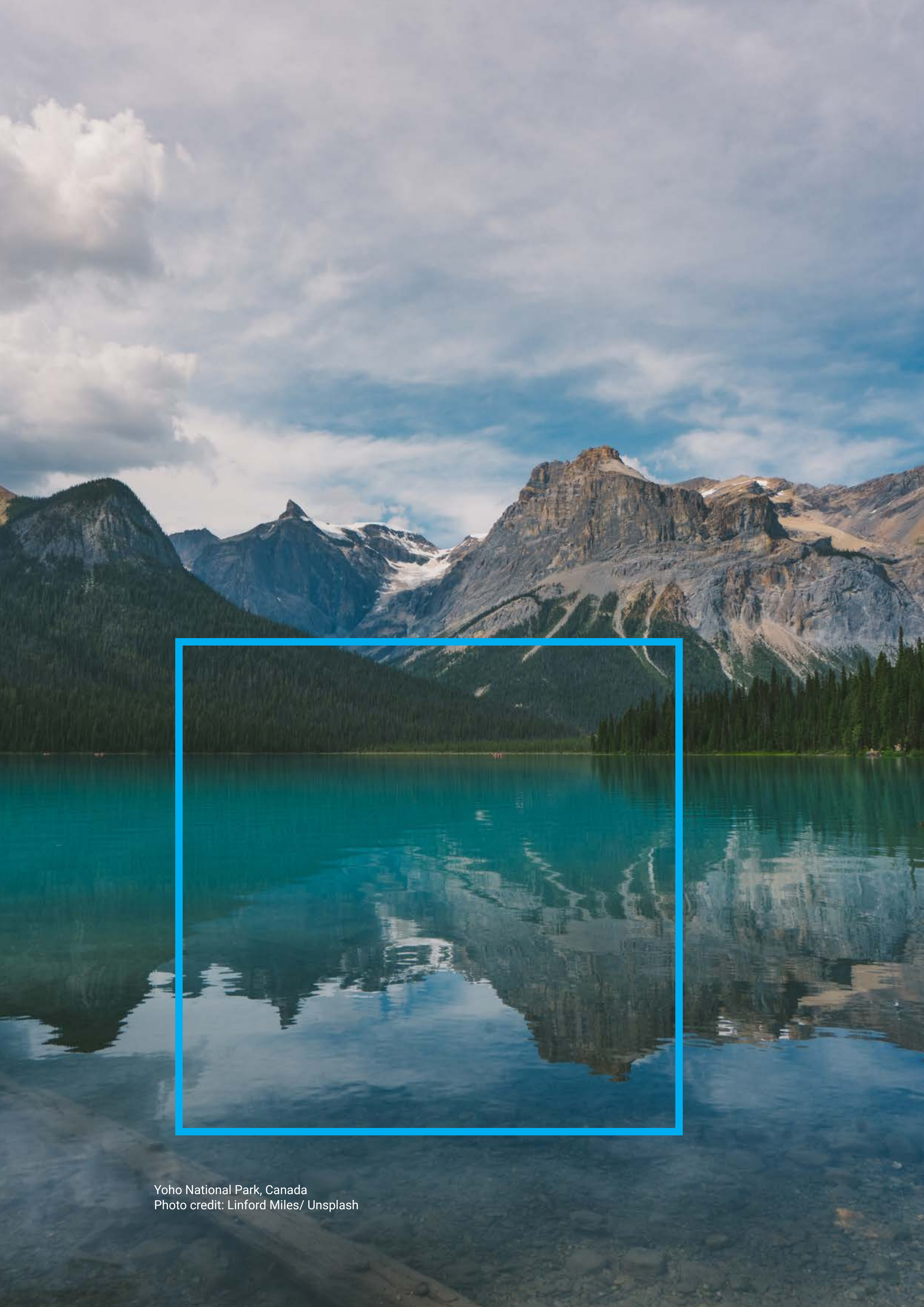
As the focus of the screening is to identify freshwater ecosystems that are either good/important or poor/at risk, it is not necessary at this stage to develop a detailed classification system for ecological status. To meet the objectives of this step, the most important classes could simply be 'good', ´moderate´ and 'poor', or equivalent. Identifying ecosystems likely to be in 'good' condition can help with setting threshold values for indicators (see Assessment Phase), as well guiding decisions about where protection measures may need to be put in place to ensure ecosystems and their services are maintained. Identifying those ecosystems likely to be in 'poor' condition, or those at significant risk of degradation, can help with the prioritization of monitoring and mitigation activities. The number of categories between these two extremes depends on the level of ambition and level of information available at this stage. At the most basic level, all ecosystems not identified as 'good' or 'poor', could be classed in a single class (e.g. 'moderate'). However, it is recommended that the 'moderate class' is divided into 2 or 3 more classes to provide more useful information for decision-making. Where precise reference conditions or thresholds between classes are difficult to quantitatively define, it is important to indicate the rationale for a particular rating – particularly for future assessments and comparisons. The development of a more detailed classification system can be undertaken during the Assessment Phase. However, if a more detailed classification system already exists, or there is a desire to define one at this stage, then the step – define ecological status classes – (see Assessment Phase), may be undertaken in conjunction with the desktop screening.

Further guidance on the desktop screening step is provided in Section 4.4 of Volume 4.

The Identification Phase, including desktop screening, can provide useful information as to the existence and estimated ecological status of ecosystems in a country,[162] even if more detailed monitoring and assessment (as addressed in the Assessment Phase) has not yet been undertaken.

157 http://whc.unesco.org/en/list/
158 http://whc.unesco.org/en/danger/
159 http://www.biodiversitya-z.org/content/key-biodiversity-areas-kba
160 https://iucnrle.org
161 https://www.iucn.org/theme/protected-areas/our-work/iucn-green-list
162 DWS, South Africa. 2014. A Desktop Assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per Sub Quaternary Reaches for Secondary Catchments in South Africa. Compiled by RQIS-RDM: https://www.dwa.gov.za/iwqs/rhp/eco/peseismodel.aspx


Lafayette, United States
Photo credit: Kyle Glenn / Unsplash



Yoho National Park, Canada
Photo credit: Linford Miles/ Unsplash

7 Monitoring (Assessment Phase)[163]

Assessment Phase
- Set Ecological Status Thresholds & Targets
- Monitor
- Evaluate & Report

Generally, ecological monitoring is done to:[164]
- Assess the effectiveness of policy or legislation designed to protect ecosystems
- Assess regulatory instruments (performance or audit function)
- Detect emerging changes ('early warning') in ecosystems

The purpose of ecological monitoring in the context of this volume is to support management activities. This means that data collection needs to be able to determine:
- The Ecological Status Class of the ecosystem
- Whether the present Class for individual indicators and the overall ecological status of each ecosystem conforms to the target Classes agreed on in the previous step

The results from the monitoring activity are used in evaluation and reporting (which is not discussed in detail in this volume).

Different types of monitoring are used, for a variety of purposes:[165]
- Survey: usually a one-off descriptive exercise that is used to describe the habitats at a site or to map the distribution of a species
- Surveillance: a replicable survey, done to detect trends in habitats, populations and environmental change
- Experimental management: used to test the effects of different management practices
- Environmental impact assessment: which assesses the likely effects of a development or incident
- Research: carried out to increase knowledge about a species or habitat, through ecological modelling, population viability analysis and demographic studies

All of these types of approaches can contribute information to monitoring ecological status. In essence, monitoring can be defined as "Intermittent (regular or irregular) surveillance carried out in order to ascertain the extent of compliance with a predetermined standard (i.e. Target) or the degree of deviation from an expected norm (Target)."[166]

163 Further guidance on monitoring is provided in sections 2.6 and 4.6 of Volume 4.
164 Hellawell, JM.1991. Development of a rationale for monitoring. In: Goldsmith B (ed) Monitoring for conservation and ecology. Chapman and Hall, London.
165 Hurford, C, Schneider, M & Cowx,I (Eds.). 2010. Conservation Monitoring in Freshwater Habitats: A Practical Guide and Case Studies. Springer
166 Hellawell, JM.1991. Development of a rationale for monitoring. In: Goldsmith B (Ed) Monitoring for conservation and ecology. Chapman and Hall, London.

SDG 6.6.1 proposes a programme with steps that address local reporting on the extent of ecosystems (volume and size) and becomes more detailed to include ecosystem health for national reporting as capacity increases.
SDG 6.3.2 indicates that an initial water quality monitoring programme should be shaped around core physico-chemical parameters and that the programme should progressively monitor a wider variety of parameters as capacity increases.
SDG 6.3.1 proposes a progressive monitoring strategy that starts with surveys to estimate wastewater production, to the use of secondary data from existing monitoring and service providers, to a full assessment based on additional monitoring to fill data gaps.

Box 11 Monitoring systems for SDG indicators 6.6.1, 6.3.2, and 6.3.1.

The monitoring step involves the following:
- Design: focuses on the basic principles to be considered in designing a monitoring programme
- Data collection: this addresses important considerations when conducting sampling surveys
- Data management and quality assurance: this addresses the collection and storage of field data, as well as considerations around calibration of instruments and laboratory handling of water quality samples

7.1 Designing Monitoring Programme

The purpose of designing a monitoring programme is to provide the context and the framework for the actual monitoring activity. Several excellent examples of monitoring programmes are available.[167,168,169,170,171] However, when designing a monitoring programme for situations where capacity and information is limited, there are a number of important practical considerations.

The initial design of the monitoring programme requires some basic information (which may have been collected in the desktop screening step in the Identification Phase):
- An inventory of available data for ecosystems for each drainage basin
- An assessment of pressures and risks for the identified ecosystems
- The identification of high-value water bodies and those most at risk

This information provides an overall view of the status quo and enables the setting of priorities for a monitoring programme. In light of these priorities, the current capacity of the monitoring programme should then be assessed. Future capacity needs can also be considered, in line with the vision and objectives.

Based on the current capacity, several questions can be addressed:
- How many of the priority water bodies would it be possible to monitor in a drainage basin within a particular time period?
- How many sites will be needed and how many can presently be monitored? This will be dependent on the ecosystem type, size, ecological diversity and the kind of indicators that need to be monitored.
- How often can sites in an ecosystem be monitored and what is the desired frequency?

167 USA: https://archive.epa.gov/emap/archive-emap/web/html/index.html
168 USA: https://www.epa.gov/hwp/integrated-assessment-healthy-watersheds
169 Australia: http://watercentre.org/portfolio/rhef/attachments/technical-reports/river-health-indicators-assessment-and-applications-for-river-management-planning-and-policy-making.
170 European Communities, 2003. Common implementation strategy for the Water Framework Directive (2000/60/EC). Guidance Document No. 7, Monitoring under the Water Framework Directive.
171 South Africa: http://www.dwa.gov.za/iwqs/rhp/naehmp.aspx

- Which indices (and constituent indicators) can be used to determine the ecological status of different ecosystems?
- Are there temporal (seasonal and annual) and spatial variabilities that need to be considered during the setting of reference conditions? The natural climatic variability of a site (e.g. flows, temperature, physico-chemical conditions, etc.) has a bearing on biological indicators. For example, the absence of suitable habitat features or natural migration may affect the abundance or frequencies of observations of biota. It follows that both spatial and temporal variability need to be considered carefully when defining reference conditions and interpreting monitoring results, as this can have a huge influence on the resulting ecological status class.[172,173,174]

The answers to these questions depend on the available technical expertise and equipment. Using this information, it may be possible to structure a budget that can, for example, make provision for a multi-year plan during which certain milestones can be set. This can take into account the different priority ecosystems to be monitored, and the need for improving equipment and expertise, and training for monitoring staff.

In addition to field monitoring, the use of Earth Observation data should also be considered as part of a complete monitoring programme, as it can provide complementary and cost-effective data. Data is often available from space agencies free of charge, though there will be costs associated with the interpretation and validation of the data at the country level.[175]

Modelling is also often an integral part of a monitoring programme, particularly for filling gaps in remote locations. National, regional and global models are available – for example for streamflow.[176,177,178] As with Earth Observation data, models require validation.

For field monitoring and ground verification, the process and criteria for selecting monitoring sites is critical, especially where reference sites, reference conditions and representivity of present ecological conditions are concerned. Ideally, this process should take place within the ecosystem classification framework. It is also important that units or sections within ecosystem types are grouped according to ecological status classes. The degree to which the status at a site or section is representative of the total area will be influenced by the variability of the ecological status in different sections. For example, a section of a river reach within a particular ecoregion delineation may actually be in a different status class to other sections because of varying local land-use impacts along the river's length. These river sections should be identified, even if this is done qualitatively using Google Earth images and local expert knowledge.

It is therefore important to be selective when choosing sites for an ecosystem – using, for example, a stratified methodology such as stratified random sampling.[179] The most scientifically rigorous approach is the probability-based selection of sampling sites, which ensures representation of a measurement or metric in an ecosystem or subsystem (e.g. the USA EPA approach[180]). However, this process is resource intensive.

172 https://www.epa.gov/sites/production/files/2015-11/documents/sampling-consideration-recreational-waters.pdf
173 Kurtz, JC, Jackson, LE, William S. Fisher, WS. 2001. Strategies for evaluating indicators based on guidelines from the Environmental Protection Agency's Office of Research and Development. Ecological Indicators. 1: 49–60
174 Jackson, LE, Kurtz, JC, & Fisher, WS (Eds.). 2000. Evaluation Guidelines for Ecological Indicators. EPA/620/R-99/005. U.S. Environmental ProtectionAgency, Office of Research and Development, Research Triangle Park, NC.
175 For more information on incorporating Earth Observation data into monitoring programmes, see:
For a service provider: http://www.eomap.com/services/water-quality/;
For Africa: http://www.tiger.esa.int/page_eoservices_wois.php
http://eo4sd-water.net; Global Earth Observation System of Systems (GEOSS) http://www.earthobservations.org/geoss.php
176 Hughes, DA (Ed.). 2005. Spatsim, An Integrating Framework For Ecological Reserve Determination And Implementation. WRC Report No: TT 245/04. South Africa.
177 http://www.hec.usace.army.mil/software/hec-ras/features.aspx
178 Hughes, DA, Desai, AY, Birkhead, AL, & Louw, D. 2014. A new approach to rapid, desktop-level, environmental flow assessments for rivers in South Africa. Hydrological Sciences Journal, 59: 1–15.
179 https://en.wikipedia.org/wiki/Stratified_sampling
180 Stevens, DL & Olsen, AR. 2004. Spatially Balanced Sampling of Natural Resources. Journal of the American Statistical Association, 99: 262-278.

For many countries, it will be necessary to follow a simplified approach that, within the stratification process, takes account of information that is already available at sites within an ecosystem. Such sites may have been monitored for some time for purposes other than ecological status assessment but they may have yielded information that can be useful in the interpretation of ecosystem condition.

If the statistical validity of an ecological status class in a section of an ecosystem needs to be determined, the number of sites will also need consideration. However, the number of sites required to generate statistical certainty may have serious expertise and budgetary implications. Often, accessing 'ideal' sites is very difficult, and may place limitations on the number of sites that can be monitored. For new monitoring programmes, the number of sites will usually be limited by budget, and available equipment and expertise.[181]

The initial monitoring survey of an ecosystem should be used for setting the baseline that represents the ecosystem status at that time. This will be the benchmark against which future status assessments will be compared[182] to determine if the desired status class is being achieved – or if there is movement either towards or away from the desired state.

In the design of an ecosystem monitoring programme, provision should be made for an adaptive approach.[183] In other words, provisions that allow changes or adaptations to a monitoring programme when shortcomings become evident.[184] Adaptive monitoring implies an active feedback loop between monitoring results and the design, implementation and review of response or management actions (Response Phase).

Over time, monitoring sites become more valuable as the amount of data collected from them increases, allowing trends to be determined (which largely negates the concern for statistical certainty associated with one-off surveys). If it is deemed necessary to change the location of sites or to add or drop sites, then consideration needs to be given to the invested value of existing sites. For example, the River Health Programme in South Africa (currently the River Ecosystem Monitoring Programme)[185] earmarked a substantial number of sites for monitoring. However, as a result of budget and other capacity constraints, the sites were consolidated and for practical purposes grouped into primary sites (that are indicated in national legislation and should always be included in monitoring), secondary sites (that provide important information and should be monitored regularly at a subnational level) and supplementary sites (that may provide important additional information that can be used for interpretation).

At the practical level, it is important that field data forms be developed to make provision for the indicator data that will be captured. Electronic forms can be developed to facilitate direct download to an electronic database. If paper forms are used, it is important that the design of forms are as close as possible to the electronic database forms in which field data will eventually be captured.

7.2 Collecting Data

This step involves the implementation of the designed monitoring activities in the previous step.

Management protocols guide sampling procedures and data management. All sampling should be supported by standard operating procedures (SOPs) and guided where possible by published national and international standards.[186]

181 Kurtz, JC, Jackson, LE, William S. Fisher, WS. 2001. Strategies for evaluating indicators based on guidelines from the Environmental Protection Agency's Office of Research and Development. Ecological Indicators. 1: 49–60
182 Karr, JR & Chu, WE.1999. Restoring Life in Running Waters: Better Biological Monitoring. Washington, DC: Island Press
183 Holling, CS (Ed). 1978. Adaptive environmental assessment and management. John Wiley & Sons.
184 Lindenmayer, DB & GE Likens. GE. 2009. Adaptive monitoring: a new paradigm for long-term research and monitoring. Trends in Ecology and Evolution. 24: 482-486.
185 http://www.dwa.gov.za/iwqs/rhp/naehmp.aspx
186 For more information, see section 4.6.4 of Volume 4. See also Clescearl, L. S., Greenberg, A. E., Eaton, A.D. (Eds). Standard Methods for the Examination of Water and Wastewater (20th ed.) American Public Health Association, Washington, DC. ISBN 0-87553-235-7.

Field monitoring activities should consider factors such as personnel safety measures, and safe practices and behaviour in the field. Labour safety legislation should be adhered to. Prior to the field survey, everyone involved should be instructed as to the details and purpose of the exercise. During the monitoring activity, it is important that the person in control of the exercise ensures that data is collected according to the methods and processes prescribed in the design.

Considerations such as permits to collect biological data and permission to access private areas should be dealt with beforehand.

All sampling equipment should be checked prior to a monitoring survey – e.g. fish and invertebrate sampling equipment, water sampling equipment and the calibration of water quality apparatus (e.g. pH, electrical conductivity and dissolved oxygen metres).[187,188]

Photographs and videos are important aids for future interpretation of results and should form part of the total record keeping exercise. Photographs should be dated and geo-referenced. For future comparability, fixed point photography should be used.[189,190]

7.3 Data Management

The basis of this step is to develop simple-to-use data storage and retrieval systems in order to compare monitoring results and access associated reports and background information.

Metadata provides data about the data. The procedures to set up metadata tables are supported by ISO 19115-1:201416 and associated metadata standards.[191] Metadata is essential for providing the context for the data and to document attributes of the collection process.

The metadata collected will be specific to each data set and should provide information on the sampling rationale and protocols, definition of indicators, taxonomy, station codes, geographic information, information on data sources, data analysis and summarizing, and data ownership. Information on SOPs should be kept updated and be easily accessible. While adhering to these requirements, it is important that countries starting an ecosystem status monitoring programme should develop a suitable database to allow for the easy storage and retrieval of data. Care should be taken when a decision is made to develop a database system to store data. Such systems may be costly, particularly if they need updating when changes to the system are required. It is therefore important to consider whether 'off-the-shelf' rather than customized database software would be more suitable.

There are a number of database and spreadsheet software packages that may be suitable. Such software also allows data to be exported and saved in formats (such as comma delimited files) that can easily be imported into other software, which can be used for data manipulation and statistical analysis.

Provision may be made to incorporate, analyse and present data in a Geographical Information System (GIS). Proprietary software is available to do this. However, if capacity or budget is limited then several freeware GIS software packages are available (e.g. QGIS - http://qgis.org/en/site/about/index.html, Mapwindow - http://www.mapwindow.org/).

It is essential that field data is captured on the database system as soon as possible after data collection.

187 Jeffrey Janik, J, Gage, RH, & Erickson, CA. 2006. Water Quality Field Manual. State Of California, Department Of Water Resources.
188 Kennard, MJ, Pusey, BJ, Allsop, Q, Perna, C, Burrows, D & Douglas, M. 2011. Field Manual Including protocols for quantitative sampling of fish assemblages, habitat, water quality and sample preservation. Australian Rivers Institute, Griffith University.
189 Benvie, N. 2013. Fixed point photography a methodology. Scottish Natural Heritage.
190 https://www.youtube.com/watch?v=LGXD1ZFVkFM
191 https://www.iso.org/obp/ui/#iso:std:iso:19115:-1:ed-1:v1:en

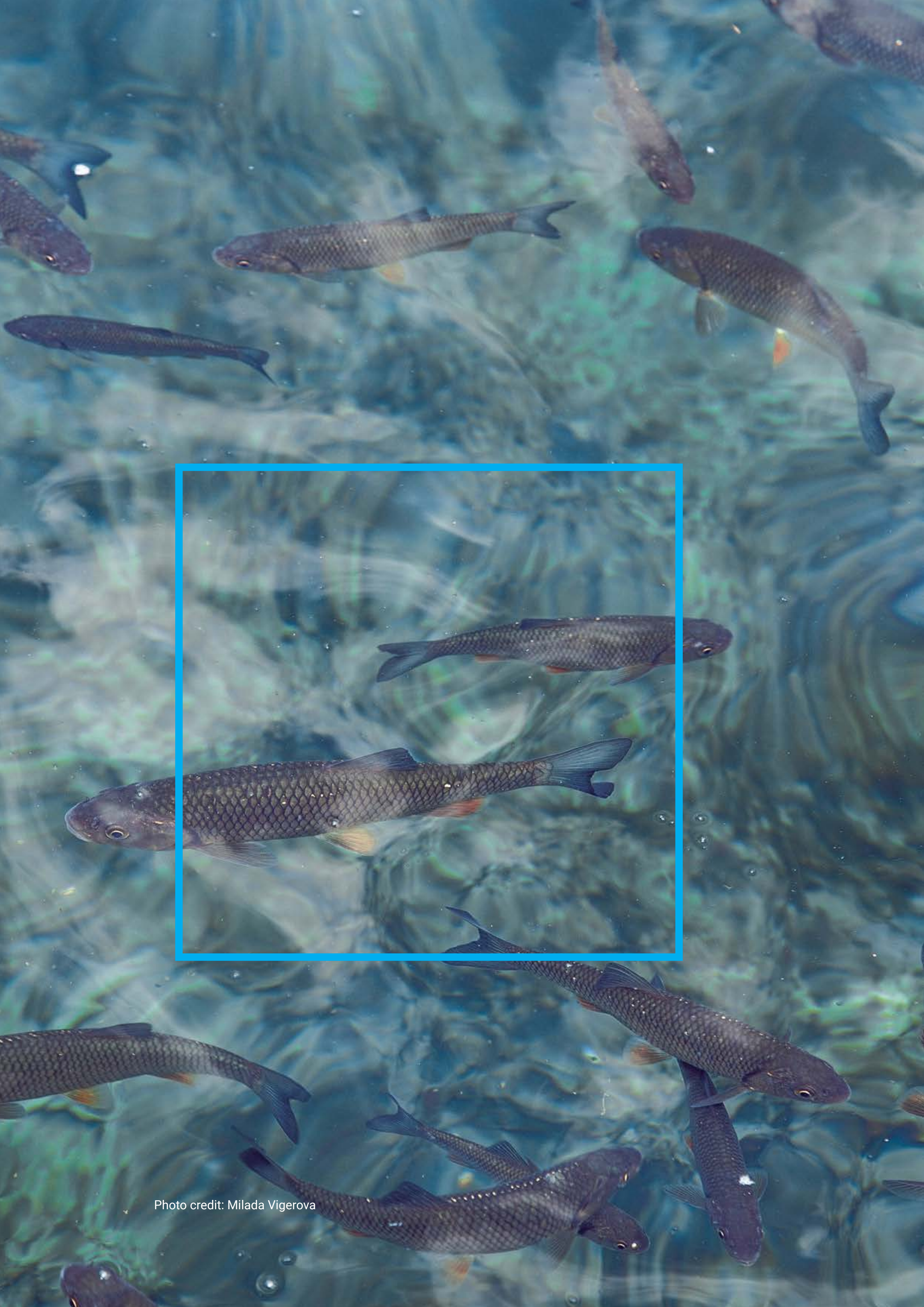


Photo credit: Milada Vigerova

8 Summary

The main purpose of this volume is to facilitate the development and refinement of context-specific, national processes to classify freshwater ecosystems, define ecological status categories and thresholds, and set management targets for ecological status. Each country has unique political, economic, environmental, social and cultural conditions, which mean that there is no blueprint for the sustainable management of all freshwater ecosystems across the world. Therefore, this volume is meant to be a 'guide' rather than a 'manual' for management. Nonetheless, the four-phase Framework presented here has been designed to be applicable and adaptable to most national circumstances. Being able to develop national monitoring processes within a common global framework facilitates cross-country collaboration and learning, not least between countries that share transboundary freshwater ecosystems.

This document is Volume 2 in the UN Environment Framework for Freshwater Ecosystem Management series. It follows Volume 1, which provides an overview of the Framework. This volume expands on some of the steps in the Framework, primarily the design of ecosystem classification systems and setting ecological status threshold values and management targets. Volumes 1 and 2 are supported by Volume 3 'Case studies',[192] and underpinned by Volume 4, 'Scientific background for regional consultations on developing water quality guidelines for ecosystems',[193] produced in 2016 during the early phases of this work.

This series has been developed in response to a request from the UN Environment Governing Council in 2013 to develop voluntary guidelines for ecosystems that could support the development of national standards, policies and frameworks.[194] This has subsequently been expanded to take into account the targets in the 2030 Agenda for Sustainable Development and feedback from countries, which suggested a framework rather than a set of water quality guidelines. There is opportunity to develop additional volumes to expand on various parts of the Framework in the future. The focus of these should address demand from countries and involve regional counterparts for further information.

This series supports countries to achieve relevant global political targets, including several Aichi Biodiversity Targets under the Convention on Biological Diversity, and the Sustainable Development Goals (SDGs). The most relevant SDG targets are 6.6 (protecting and restoring freshwater ecosystems) and 6.3 (reducing pollution and improving ambient water quality). It does not replace detailed guidance on reporting on the respective global indicators.

This series makes the case for target setting and monitoring for freshwater ecosystems, addressing different levels of capacity to do so.

192 available online at: www.unenvironment.org/water
193 UN Environment 2017. A Framework for Freshwater Ecosystem Management. Volume 4: Scientific background for regional consultations on developing water quality guidelines for ecosystems.
194 Decision 27/3, February 2013. The UN Environment Assembly was formerly the UNEP Governing Council.

Annex 1

Overview of the Framework for Freshwater Ecosystem Management as addressed in Volume 2: phases, steps and sub-steps

The table below depicts the same phases and steps as shown in Figure 1 in Section 2.1, but also includes the sub-steps, which are described in subsections of this volume. While the steps and sub-steps are presented in a logical order, they are not numbered, as they do not have to be undertaken in sequential order. In most countries, work on many of the steps will happen concurrently, as different countries are expected to be at different levels of implementation in different parts of the Framework.

Table 9 - Overview of phases, steps and sub-steps as addressed in Volume 2

Phase	Steps	Sub-steps (with section number in brackets).
Initiation	Assess capacity	(Section 5)
	Set vision/objectives	Not addressed in detail in Volume 2. See Section 2 and Volume 1
	Design Classification frameworks	Classify ecosystem types (Section 3.1)
		Potential ecosystem services per ecosystem type (Section 3.2)
		Potential indicators per ecosystem type (Section 3.3)
Identification	Identify Ecosystems and Classify by Type	(Section 6)
	Set basin context	(Section 6)
	Desktop Screening	Assess data availability by basin (Section6)
		Screen for pressures (Section 6)
		Estimate ecological status (most at risk or near-natural) (Section 6)
Assessement	Set Ecological Status Thresholds and Targets	Define ecological status classes (Section 4.1)
		Select indicators (Section 4.2)
		Set threshold values for indicators (Section 4.3)
		Set targets for ecological status (Section 4.4)
	Monitoring	Design monitoring programme (Section 7.1)
		Collect data (Section 7.2)
		Data management (Section 7.3)
	Evaluate & report	Not addressed in detail in Volume 2. See Section 2 and Volume 1

Contd...

Response	Design response	Refine objectives	Not addressed in detail in Volume 2. See Section 2 and Volume 1
		Prioritize options	
		Detailed design	
	Implement response	Review responses	
		Review framework	

Note that the majority of these steps were developed in Volume 4. Any differences between the Framework described in this volume, and in Volume 4, are described in the preface of Volume 4.

Sangha River, Republic of Congo
Photo credit: Johannes Refisch

Annex 2

Mapping the Framework for Freshwater Ecosystem Management Steps against Selected SDG Indicator Steps

The table below illustrates where similar topics are covered within the Framework for Freshwater Ecosystem Management and SDG indicators 6.6.1 and 6.3.2. The steps for the SDG indicators are as described in their respective step-by-step methodologies, available as of September 2017 from http://www.sdg6monitoring.org/home. While SDG indicator 6.3.1 on wastewater treatment is also highly relevant for freshwater ecosystems, at the time of writing, the methodology was still in a draft stage and hence is not included below. When it published, it should be available from http://www.sdg6monitoring.org/home.

Table 10 - Mapping of steps in the Framework for Freshwater Ecosystem Management against steps in SDG indicator methodologies 6.3.2 and 6.6.1.

Phase	Steps (bold), Sub-steps (not bold)	Step	6.3.2 / 6.6.1c Water Quality	Step	6.6.1a Spatial Extent	Step	6.6.1b Water Quantity	Step	6.6.1d Ecosystem Health
Initiation	Assess capacity	1	Assess monitoring capacity	Not explicitly included					
	Set vision/ objectives		Partially set in SDG 6.3	Partially set in SDG 6.6.1					
	Classification frameworks	2	(Broad classification)	1	(Broad classification in methodology)				
	Classify ecosystem types	2	waterbodies, not ecosystems	1	(Broad classification in methodology)				
	Potential ecosystem services per type		not included		not included				
	Potential indicators per type		Sections 2.3.1, 2.3.2		This is a 'parameter', set in methodology			2	Select methods for monitoring health of each type of ecosystem

Identification	Identification & classification	2	Identify & delineate waterbodies	1	Select ecosystems to monitor				
	Set basin context	2	Identify & delineate waterbodies	1	Select ecosystems to monitor	1	Select ecosystems to monitor		
	Screening		Not included	Not included					
	Data availability by basin	1	Assess monitoring capacity	Discussed in section 5.1 (not an explicit step).					
	Pressures		Not included	Not included					
	Estimate status (most at risk or near-natural)		Not included	Not included					
Assessement	Target setting	4	Collect data for target setting	Section2 & 5.2 (not an explicit step)					
	Define ecological status classes	4	Collect data for target setting	Section2 & 5.2 (not an explicit step)					
	Select indicators		Set in SDG 6.3.2		Set in SDG 6.6.1		Set in SDG 6.6.1	2	Select methods for monitoring health of each type of ecosystem
	Set threshold values for indicators	4	Collect data for target setting	Sections 2 & 5.2 (not an explicit step)					
	Set targets for ecological status			Sections 2 & 5.2 (not an explicit step)					
	Monitoring	3	Select monitoring locations	Sections 3.1 & 5.1 (not an explicit step)				2	Select methods for monitoring health of each type of ecosystem
	Design monitoring programme								
	Collect data	5	Collect data for indicator calculation	2	EO data to quantify change in extent	2	Data collection	3	Implement methods to monitor health
				3	Ground-based survey to verify EO data				
				4	Ground-based survey to evaluate change in extent				
	Data management		Section 3.3 of s-b-s guide, though not an explicit step	5	Data management (of EO and survey data)	3	Data management	4	Data management
	Evaluate & report	6	Classify water quality	6	Indicator Calculation (% change of spatial extent)	4	Indicator Calculation (% change of water quantity)	5	Indicator Calculation (% change of health)
		7	Indicator calculation						
		8	Report indicator	Not explicitly covered, but discussed in Section 4. There is a separate template for reporting on indicator 6.6.1.					

Response	Design response	Phase 4 not a part of 6.3.2 or 6.6.1		
	Refine objectives			
	Management options			
	Detailed design			
	Implement response			
	Review	9	Programme review	Not an explicit step

Notes

Freshwater ecosystems such as wetlands, rivers, and lakes are indispensable for life on our planet and vital for directly ensuring a range of benefits and services fundamental to the environment, society and the economy.

However, they face serious pressures which affect their ability to provide those services, such as pollution, over-extraction and encroachment from urban and agricultural development.

One of the main challenges in managing freshwater ecosystems lies in finding the balance between short-term socioeconomic development objectives and the need to protect and restore freshwater ecosystems to support more sustainable, long-term socioeconomic wellbeing.

UN Environment has developed a publication series entitled 'A Framework for Freshwater Ecosystem Management'. The main aim of the series is to support countries to sustainably manage freshwater ecosystems. In doing so, it supports national and international goals related to freshwater ecosystems, such as certain Aichi Biodiversity Targets and Sustainable Development Goal (SDG) targets. The series currently consists of four volumes:

- Volume 1: Overview and guide for country implementation
- Volume 2: Technical guide for classification and target-setting
- Volume 3: Case studies
- Volume 4: Scientific background for regional consultations on developing water quality guidelines for ecosystems

This volume, 'Technical guide for classification and target-setting', describes aspects of the Framework in more technical detail: classification systems for freshwater ecosystem types, setting targets for ecological status, and monitoring progress against these targets. It is primarily aimed at government agency staff responsible for the sustainable management of freshwater ecosystems.

UN environment