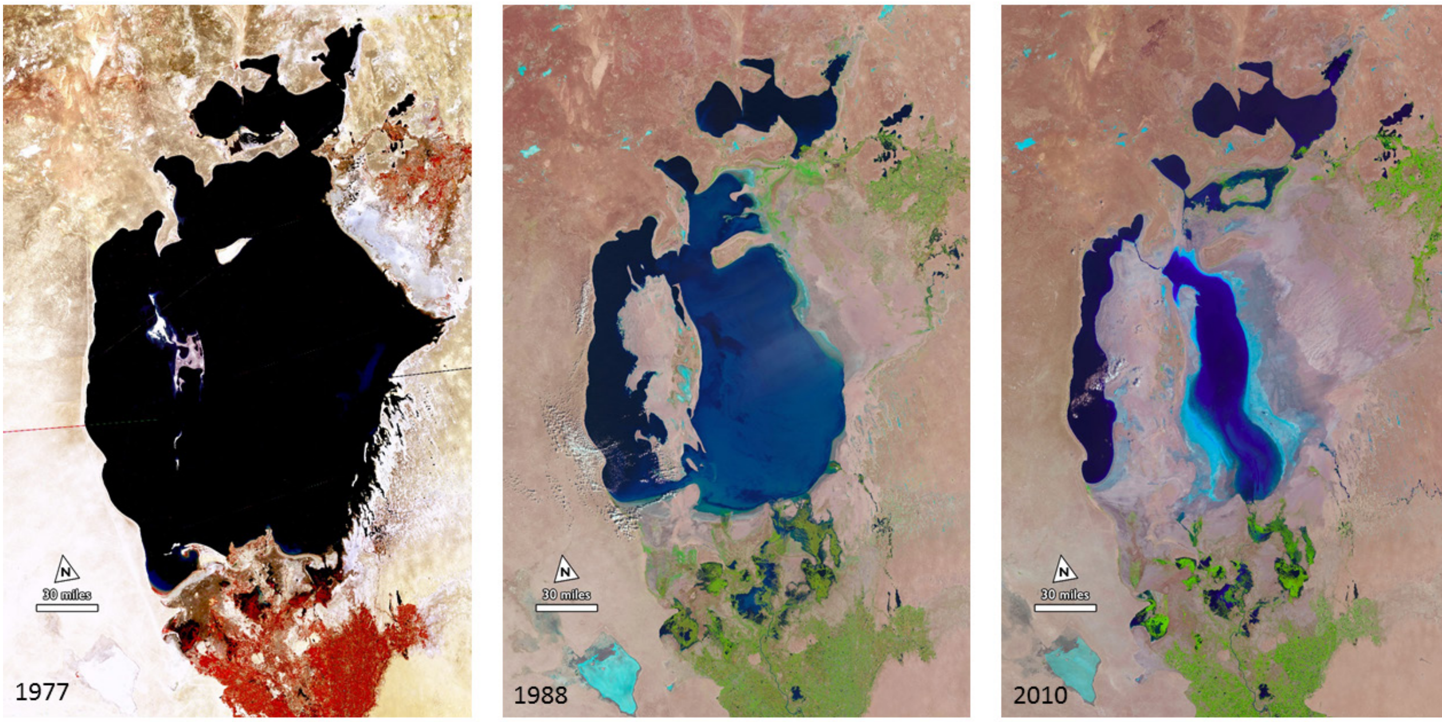


Guideline and indicators for Target 6.6 of the SDGs: “Change in the extent of water-related ecosystems over time”

Chris Dickens, Lisa-Maria Rebelo, Luxon Nhamo

Citation

Dickens, C., Rebelo, L-M., and Nhamo, L.(2017) *Guidelines and indicators for Target 6.6 of the SDGs: Change in the extent of water-related ecosystems over time.* Report by the International Water Management Institute. CGIAR Research Program on Water, Land and Ecosystems (WLE). 44p.

Front cover image: Landsat images of the Aral Sea, produced by USGS EROS Data Centre

Disclaimer

Prepared as a contribution to the SDG agenda by the International Water Management Institute (IWMI) with additional support by United Nations Environment.

Guidelines and indicators for Target 6.6 of the SDGs: “Change in the extent of water-related ecosystems over time”

Chris Dickens, Lisa-Maria Rebelo, Luxon Nhamo

SUMMARY

Note that this guideline should be read in conjunction with the Global Expanded Monitoring Initiative (GEMI, 2017) “the Step-by-step monitoring methodology for SDG indicator 6.6.1”.

This guideline provides supporting information to assist with implementation of monitoring procedures for Target 6.6 indicator, which focuses on protecting and maintaining water-related ecosystems.

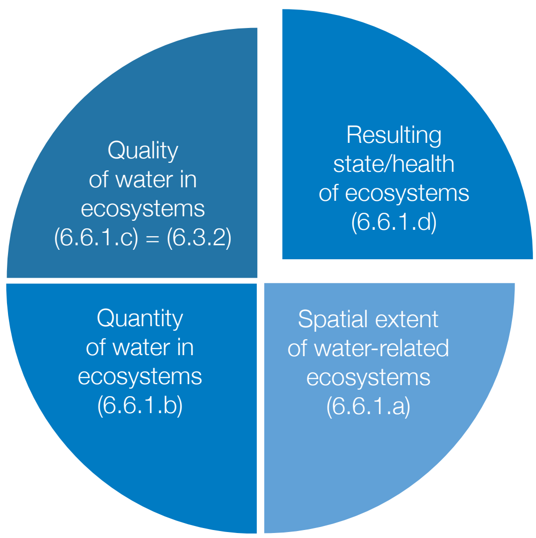
The indicator for Target 6.6.1: Change in the extent of water-related ecosystems over time

The indicator for Target 6.6.1 brings together a number of sub-indicators all of which measure and report on a different but essential component of Target 6.6. These components are illustrated in Figure 1.

The results from the sub-indicators are aggregated to form a single score for the 6.6.1 indicator, but the component data remain available as an invaluable measurement of the different ecosystem components that will allow for more comprehensive ecosystem management at the local and national level.

See the GEMI (2017) method document for a summary of this method. What is presented here is additional supporting information.

FIGURE 1. SUB-INDICATORS FOR THE BASIC 6.6 TARGET USED FOR GLOBAL REPORTING I.E. 6.6.1.A + 6.6.1.B + 6.6.1.C.



Sub-indicator 6.6.1.d is evaluated separately for 2017 and is used for national and global reporting in the future – see Table 4 and Figures 5 and 6. The description of progressive monitoring in Table 4 defines the content of each sub-indicator and the limitations to implementation.

ACKNOWLEDGMENTS

The authors would like to thank firstly Matthew McCartney for his leadership and comments; the staff of UNEP/UN Environment, especially Joakim Harlin, Lis Bernhardt, Stuart Crane, and from the Ramsar Convention on Wetlands, Ania Grobicki and later Martha Rojas-Urrego for their inputs. Also, all those who attended the Earth Observation (EO) workshop that was convened in Switzerland in November 2015 and where valuable contributions were made to defining just what EO could do for this type of monitoring. We particularly thank Marc Paganini of the European Space Agency who contributed to the formatting of the workshop and the drafting of the final report (Dickens and Rodila 2015). On the same subject, Kathrin Weise has contributed much valuable insight into the EO approach.

Key in this indicator development was the Task Team appointed by UNEP that operated during 2014 and structured the basics of the method. They included Thomas Chiramba, UNEP; Simone Grego, WAP (United Nations World Water Assessment Programme); David Coates, CBD (Secretariat on the Convention on Biological Diversity); Isabelle Fauconnier, IUCN (International Union for Conservation of Nature); Paul Ouedraogo, RAMSAR (the Ramsar Convention on Wetlands); Paul Orengoh, RTI International); Betsy Otto (Charles Iceland as alternate), WRI (World Resources Institute); Vladimir Smakhtin, UNU-INWEH (United Nations University - Institute for Water Environment and Health); and George Van Houtven (RTI International).

The following also contributed valuable comments during the method development: Geert-Jan Nijsten and Andreas Antoniou, IGRAC (International Groundwater Resources Assessment Centre) made substantial improvements to the groundwater estimations. Karen Villholth, Brian Richter, Jac van der Gun, Aurélien Dumont, Martina Flörke, Peter Koefoed-Bjornsen, Graham Jewitt, Ken Irvine, Mark Smith, and Matt Walpole also made valuable comments to the report.

Finally thanks to Kingsley Kurukulasuriya who undertook the thankless task of editing the text and to Michael Dougherty who did the final layout.

This research was/is carried out under the CGIAR Research Program on Water, Land and Ecosystems with support from CGIAR Fund Donors (http://www.cgiar.org/about-us/ourfunders/) including: the Australian Center for International Agricultural Research (ACIAR); Bill and Melinda Gates Foundation; Netherlands Directorate-General for International Cooperation (DGIS); Swedish International Development Cooperation Agency (Sida); Swiss Agency for Development Cooperation (SDC); and the UK Department of International Development (DIFD).

United Nations Environment Programme (UNEP) now UN Environment provided additional funding during 2016 and 2017.

The CGIAR Research Program on Water, Land and Ecosystems (WLE) combines the resources of 11 CGIAR centers, the Food and Agriculture Organization of the United Nations (FAO) and numerous national, regional and international partners to provide an integrated approach to natural resource management research. WLE promotes a new approach to sustainable intensification in which a healthy functioning ecosystem is seen as a prerequisite to agricultural development, resilience of food systems and human well-being. This program is led by the International Water Management Institute (IWMI), a member of the CGIAR Consortium, and is supported by CGIAR, a global research partnership for a food-secure future.

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ACRONYMS

IAEG	Inter-Agency Expert Group
CBD	Secretariat on the Convention on Biological Diversity
CEN	Comité Européen De Normalisation
CWSI	Canadian Water Sustainability Index
DO	Dissolved Oxygen
EC	Electrical Conductivity
EO	Earth Observation
ESA	European Space Agency
GEMI	Global Expanded Monitoring Initiative
GGIS	Global Groundwater Information System (
GGMN	Global Groundwater Monitoring Network
GIS	Geographic Information System
IGRAC	International Groundwater Resources Assessment Centre
IUCN	International Union for Conservation of Nature
IWMI	International Water Management Institute
MEA	Millennium Ecosystems Assessment
NASA	National Aeronautics and Space Agency
OP	Orthophosphate
PRI	Policy Research Initiative
SDGs	Sustainable Development Goals
SMAP	Soil Moisture Active Passive
SWOT	Surface Water and Ocean Topography
TON	Total Oxidized Nitrogen
UN	United Nations
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNGA	UN General Assembly
UNU-INWEH	United Nations University - Institute for Water Environment and Health
USDA	United States Department of Agriculture
USEPA	United Environmental Protection Agency
WFD	Water Framework Directive
WJWSI	West Java Water Sustainability Index
WRI	World Resources Institute
WSI	Watershed Sustainability Index
WWAP	United Nations World Water Assessment Programme

Okavango Delta in Botswana. *Photo:* Chris Dickens/IWMI

1. INTRODUCTION

On 18th September 2015 the declaration at the UN General Assembly (UNGA) for "Transforming Our World: The 2030 Agenda for Sustainable Development" (UNGA 2015) was accepted by the UN. This Agenda documented the 17 Goals and 169 Targets deemed necessary to monitor and realize if society is to achieve a sustainable future. Taken together, the globally agreed goals and targets are expected to provide a landmark framework that guides countries towards sustainable development.

This report presents guidelines for practical application of one of the 169 targets that serve the Sustainable Development Goals (SDGs):

Goal 6: Ensure availability and sustainable management of water and sanitation for all.

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 of water-related ecosystems over time.

This indicator comprises four sub-indicators:
6.6.1.a. Spatial extent
6.6.1.b. Water quantity
6.6.1.c. Water quality
6.6.1.d. Ecosystem health

Water-related ecosystems influence the water cycle, comprise the source of water for people and are, therefore, of direct importance to the achievement of Goal 6. Implementation of the monitoring of Target 6.6 will represent the first time that a global initiative has set out to monitor water-related ecosystems in such detail and with the endorsement of the global community. This builds substantially on the comprehensive monitoring of the extent of wetlands developed by the Ramsar Convention of Wetlands over many years, with participation by most of the countries of the world.

The loss of water-related ecosystems can lead to increasing water insecurity. This needs to be seen within the context that water-related ecosystems are vital to urban and rural communities, providing a variety of social and economic benefits (Wilen and Bates 1995; Zedler and Kircher 2005). Monitoring and management of these ecosystems to prevent further loss are important as a part of ensuring a sustainable future.

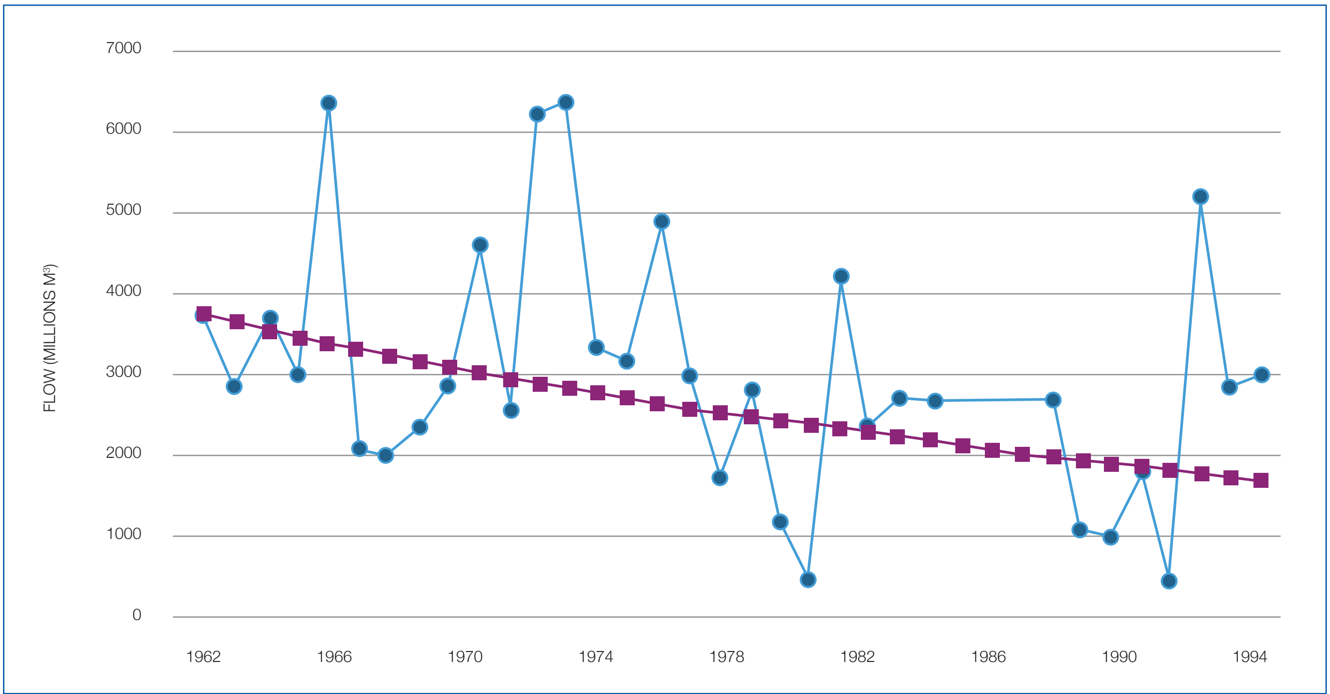
Without proper management, the generally increasing exploitation of these ecosystems is resulting in degradation (Davidson 2014; Sanchez et al. 2015). By way of example, the rate of loss of global wetlands (spatial area) between 1900 and 2000 is estimated to be around 69-75% (Davidson 2014),

> Definition: Water-related ecosystems
> Water-related ecosystems are those dominated by freshwater or brackish water and include vegetated wetlands, open water bodies such as lakes and reservoirs, rivers and estuaries and even groundwater. The water aspects of these ecosystems that play an important role in the water cycle, such as mountains and forests, are included.
>
> Note that the definition excludes marine ecosystems but includes systems where freshwater and salt water may alternate or mix and which are an integral part of river ecosystems, e.g., estuaries and mangroves.

of which approximately 40% was lost between 1970 and 2008 (Ramsar Convention on Wetlands 2015). Considering the example of river flows (quantity of water in rivers), as an example (and there are multiple examples!) the flow in the Thukela River in South Africa is falling over time (Figure 2). This means less water, less water-related habitat and consequently less provision of ecosystem services that rely on the presence of that water, e.g., less water for domestic and agricultural abstraction, less water for fish populations, and less capacity to carry away and process organic pollutants, etc. Many rivers and lakes around the world are facing similar threats, with iconic examples such as the Aral Sea and Lake Chad affected as a result of upstream water withdrawals to the point where their ecosystems have all but collapsed and together with that, the provision of ecosystem services. Also degrading ecosystem are pollution, alien invasions, fragmentation of ecosystems, altered flows, unsustainable harvesting of fish and other organisms, and many other anthropogenic stressors, leading to major threats to water-related ecosystems and their services (see the next section below). The Millennium Ecosystems Assessment (MEA 2005) had as its Finding No. 1, that "Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet rapidly growing demands for food, freshwater, timber, fiber, and fuel. This has resulted in a substantial and largely irreversible loss in the diversity of life on Earth". That same report also noted that "approximately 60% (15 out of 24) of the ecosystem services examined during the Millennium Ecosystem Assessment are being degraded or used unsustainably, including freshwater, capture fisheries, air and water purification, and the regulation of regional and local climate, natural hazards, and pests". The MEA also notes that "the use of two ecosystem services—capture fisheries and freshwater fisheries—is now well beyond levels that can be sustained even at current demands, much less at future ones".

To assist efforts to protect and restore water-related ecosystems, comprehensive and consistent approaches need to be implemented to assess rates of loss and changes

FIGURE 2. AVERAGE FLOW IN THE THUKELA RIVER OVER TIME (SOUTH AFRICAN NATIONAL SOE REPORT).



SOURCE: http://www.ngo.grida.no/soesa/nsoer/indicatr/fig3_13d.htm

in environmental condition. The global monitoring program encapsulated by Agenda 2030 and the SDGs, provides a significant step towards redressing this issue by setting out to monitor and provide data and information on the state of water-related ecosystems through the provisions of Target 6.6. Agenda 2030 also includes other targets that support some aspect of ecosystems management; 6.3.2 monitors ambient water quality and 6.4.2 water stress, and 6.5 looks at IWRM and transboundary management of water resources. There are also other Goals, whose monitoring will have an impact on water-related ecosystems, including SDG 13 on climate change, and SDG 15 on terrestrial ecosystems, in particular, 15.1. "By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements". SDG 15.2 seeks to protect forests; 15.3 to prevent desertification; 15.4 on mountain ecosystems; and 15.5 on the degradation of natural habitats and loss of biodiversity. When all these, plus others in a less direct way, are monitored and local actions taken to address what is revealed by the monitoring, then there is a good chance that we will be moving towards a sustainable future.

1.1. Ecosystem services associated with Target 6.6

The inclusion of Target 6.6 in the SDGs reflects the growing recognition of the importance of ecosystems for sustainable development[1]. Over the past decade, the consideration of ecosystems in the global development agenda (MEA 2005; Russi et al. 2013) has highlighted that healthy ecosystems are essential to maintain the provision of services which underpin society, with the Millennium Ecosystems Assessment (MEA 2005) giving an estimated value of wetland ecosystem services at USD 15 trillion for 1997. Ecosystem services are the "benefits people obtain from ecosystems". They include *provisioning services* such as food, water, timber, and fiber; *regulating services* that affect climate, floods, disease, wastes, and water quality; *cultural services* that provide recreational, aesthetic, and spiritual benefits; and *supporting services* such as soil formation, photosynthesis, and nutrient cycling (Figure 3). Human society, no matter how developed, remains fundamentally dependent on the flow of ecosystem services from natural ecosystems. Rural people may live much closer to the ecosystem and may be more immediately dependent on services for their livelihood, while urban communities may be buffered from short-term and spatial changes in the ecosystem; but in reality, they are no less dependent despite often being unaware of their dependence.

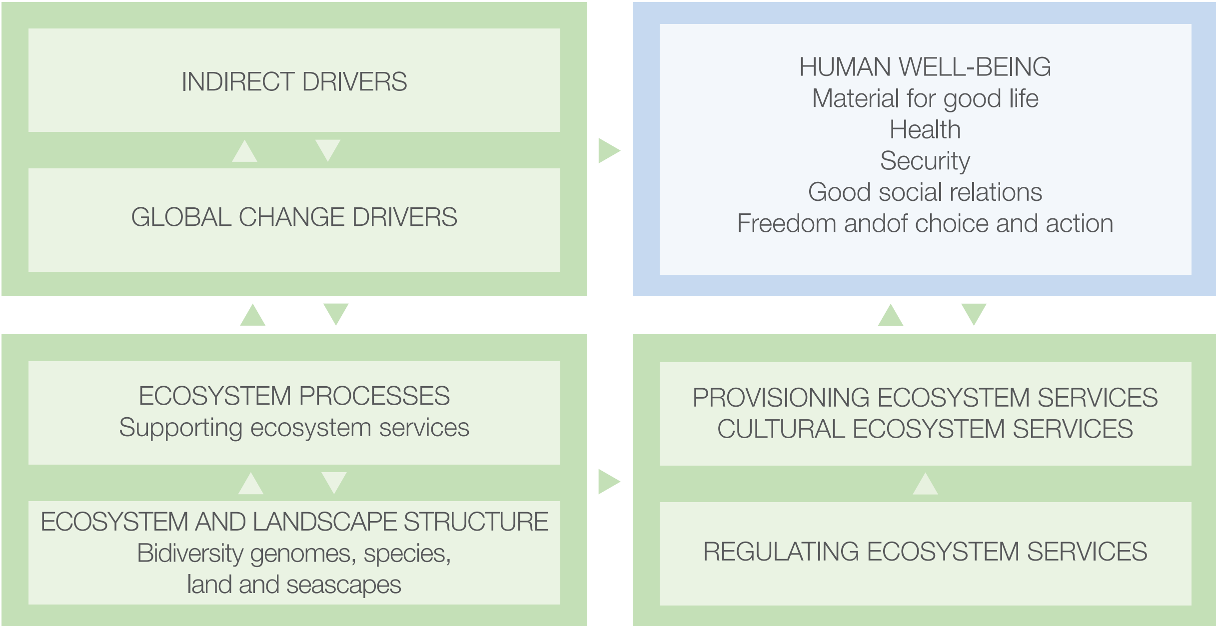
The overarching theme of Goal 6 is the provision of water and sanitation to people; within this Goal, Target 6.6 addresses the protection of water-related ecosystems. *It is important to appreciate that Target 6.6 is not about ecosystem protection per se, but that in the context of the Goal 6 description, it is about the protection of ecosystems to ensure that they continue to provide sustainable water and sanitation services to society. The importance of ecosystems is ultimately measured by the services they provide to society.*

1.2. Objectives of this guideline

This report presents a guideline in support of the indicator method for Target 6.6.1 (GEMI 2017), titled "Step-by-step monitoring methodology for SDG indicator 6.6.1". Of necessity, this method was produced in an abbreviated format; and, in support of this, this report provides guidelines

[1] Definition from Ramsar Convention Article 1.1. In addition, the Ramsar Classification System for Wetland Type was approved by Recommendation 4.7 and amended by Resolution VI.5 of the Conference of the Contracting Parties which confirms the inclusion of subterranean hydrological systems within the definition.

FIGURE 3. ECOSYSTEMS AND THEIR RELATION TO SOCIETY



STRUCTURE OF THIS GUIDELINE

This report should be viewed together with GEMI (2017) which it supplements and which contains the basic foundation on which this report is built. This report provides the following sections:

An introduction to the 6.6.1 indicator and methods

This section describes the indicator itself, comprising four sub-indicators. It indicates what is included and excluded from the method, the interlinkages with other indicators, and how the basis of this method depends on monitoring the percentage of change over time. This means that there has to be a starting point or reference condition, which is also defined. The method for calculation of the percentage change is also given, for both component methods and the aggregated 6.6.1 method. It also then provides direction for reporting and implementation.

Sub-indicator 6.6.1.a: Percentage change in the extent of water-related ecosystems over time

This sub-indicator measures the geographic or spatial extent of all water-related ecosystems. While this is focused on the extent of vegetation dominated wetlands, it also applies to other water-related ecosystems.

Sub-indicator 6.6.1.b: Percentage change in quantity of water over time

This sub-indicator reflects the quantity of water in any water-related ecosystem where this is measurable and important. Thus, the flow of rivers dominates, as does the volume of water in lakes and artificial reservoirs. Less obvious is the quantity of groundwater. Difficult to measure is the quantity of water in palustrine "swampy" wetlands, soil water, and snow and ice, which are excluded from the method.

Sub-indicator 6.6.1.c: Percentage change in quality of water over time

The quality of water is an important dimension of any water-related ecosystem; however, these data are collected under the direction of Target 6.3.2 and the results simply imported here for inclusion in the aggregated 6.6.1 result.

Sub-indicator 6.6.1.d: Percentage change in the state of water-related ecosystems over time

The ecological health or state of ecosystems is the ultimate arbiter of how things are going in that ecosystem. Each of the different ecosystems types, in the different parts of the globe, will require different methods for assessment of state. These are not stipulated in this method, but the final output should be the change in state over time measured as a percentage. Note that this sub-indicator need not be reported during the roll-out phase during 2017 but that it will be reported in later years.

to assist implementers with some of the background detail not contained in the short version. This document is intended as a guideline only, and any implementer will need to adapt the details of the methods to suit data availability and local conditions. The step-by-step monitoring methodology for indicator 6.6.1 (GEMI 2017) does not prescribe any particular method for data collection, but rather enables countries to use the method most appropriate for their situation. Thus, while one country may use flow gauging stations to monitor stream flow, another country may use hydrological models, both having the same output. All that is required is that the results fit with the overall objectives of the 6.6.1 Target. Thus, countries need to participate in the way that best suits them but within the constraints and guidelines contained in the GEMI (2017) methodology and further elaborated in this report.

Note that this report includes text also presented in the GEMI (2017) "Step-by-step monitoring methodology for SDG Indicator 6.6.1" document, without specific acknowledgment.

Measuring and monitoring the status of an ecosystem require one or more indicators that are fit for the purpose in terms of GEMI (2017). The norm is that the indicator used should comply with the common 'SMART' rationale, i.e., it should be *specific, measurable, achievable, realistic/ relevant* and *time-bound* (Edvardsson 2004; Niemeijer and de Groot 2008). The procedures proposed here consider these criteria.

2. THE 6.6.1 INDICATOR: CHANGE IN THE EXTENT OF WATER-RELATED ECOSYSTEMS OVER TIME – AN OVERVIEW

2.1. Introduction to 6.6.1.

The first intention of the 6.6.1 indicator was to track the change in extent of wetland ecosystems; however, during the drafting process this was expanded by the Inter Agency Expert Group (IAEG) for the SDGs to ***"Change in the extent of water-related ecosystems over time"***. By doing this the IAEG included all water-related ecosystems and not just "wetlands" and also included quantities of water.

In view of the title of Goal 6 (*Goal 6: Ensure availability and sustainable management of water and sanitation for all.*), the objective is about water and sanitation services for people, and for this reason only freshwater -- and not saltwater -- ecosystems are included here. Targets and indicators of a more conservation focus are generally included under Goal 15 which is about protecting, restoring and sustainably using terrestrial ecosystems but which includes conservation of water ecosystems (SDG 15.1).

This indicator tracks changes over time in the extent of water-related ecosystems (GEMI 2017). It uses the imminent date of 2020 to align with the Aichi Targets of the Convention of Biodiversity, but will continue beyond that date to align with the rest of the SDG Targets set at 2030. Whereas all ecosystems depend on water, some ecosystems play a more prominent role in the provision of water-related services to society. Consequently, for the purpose of global monitoring, the indicator focuses on the following ecosystem categories: vegetated wetlands (swamps, swamp forests, marshes, paddies, peatlands and mangroves), open water (rivers and estuaries, lakes and reservoirs), and groundwater aquifers. Note that this indicator method defines "extent" as "the size or area of something" (McMillan Dictionary), thus going beyond spatial area to include other size (quantitative) measures of water-related ecosystems, i.e., quantity, quality and also state of health.

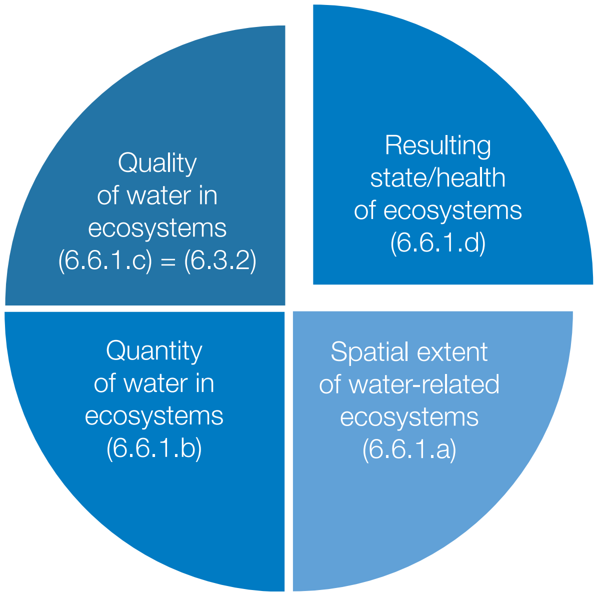
Three principle sub-indicators describing aspects of these ecosystems are monitored to describe the extent for global comparison, with a fourth sub-indicator for more advanced in-country monitoring:

I. The *spatial* extent of water-related ecosystems,
II. The *quantity* of water contained within these ecosystems,
III. The *quality* of water within these ecosystems, and
IV. The *health* or state of these ecosystems.

This indicator responds to Goal 6 in that it seeks to provide data and information to enable management and protection of water-related ecosystems so that ecosystem services, especially those related to water and sanitation, continue to be available to society. It responds to the Target which seeks to "protect and restore water-related ecosystems" by providing information on the spatial extent of these ecosystems, the quantity and quality of water within them and their health (Figure 4). All these components are necessary to provide sufficient information to protect and restore these ecosystems. However, of necessity, it does not cover every situation and there will be ecosystems related to water which do not get included, or where the specific impacts are not detected by the methods included here, e.g., saltwater ecosystems such as coral reefs and the coastal inshore are not included here. Nor are mountains, forests or drylands specifically targeted, but rather the water ecosystems themselves are examined. This may result in failure to detect issues related to these ecosystems where they do not impact on the water ecosystem, but it is intended that these issues will be covered by other Targets and indicators.

The ecosystems that have been included for monitoring as part of the 6.6.1 indicator are represented in Table 1.

FIGURE 4. SUB-INDICATORS FOR THE BASIC 6.6 TARGET USED FOR GLOBAL REPORTING I.E. 6.6.1.A + 6.6.1.B + 6.6.1.C.



Sub-indicator 6.6.1.d is evaluated SEPARATELY for the baseline in 2017 and is used for national reporting but also for future reporting – see Table 4 and Figures 5 and 6. The description of progressive monitoring in Table 4 defines the content of each sub-indicator and the limitations to implementation.

Whether estuaries should be included in SDG indicator 6.6.1 has been considered because of the saltwater presence. Mangroves are generally found in estuaries, so the same question applies here. In both cases, these ecosystems are on the cusp between freshwater and saltwater environments and, at times, are dominated by freshwater, and have characteristics of both, so it was decided to include them in the monitoring of 6.6.1.

Whether groundwater should be included as an ecosystem category has also been considered. While groundwater may contain a few and limited biological components, what suggests that groundwater should be included as an ecosystem category is its close association with surface-water ecosystems and associated ecosystem services (Brauman et al. 2015).

2.2. Omissions from this method

In the definition of Target 6.6 itself (*by 2020 to protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes*) these water-related ecosystems include mountains, forests, wetlands, rivers, aquifers and lakes. Some of these ecosystems, in particular, mountains and forests, play a pivotal role in water-related ecosystems, but they are not themselves included in this method. However, the wetlands and other water-related ecosystems associated with the mountains and forests (e.g., rivers passing through, or forested wetlands/swamps) are indeed monitored. Thus, no monitoring is recommended for mountain and forest ecosystems in general, which are, anyway, specifically catered for in Goal 15 (Target 15.1, 15.2 and 15.4) which has a conservation focus. The same applies to marine ecosystems such as coral reefs and the coastal inshore which are included in the Ramsar definition of wetlands (Ramsar 1971) and are covered under Goal 14. Estuaries and mangroves are however included as these are at the transition of freshwater and salt water, and also form an integral part of river ecosystems so that they could not be excluded.

Interactions of groundwater and surface water are key to understanding the state of water-related ecosystems as groundwater contributes the base-flow of many rivers and to wetlands too when rainfall and surface runoff are absent. Determination of this relationship is complex as it requires an understanding of the groundwater variability, its contribution to streamflow or wetland hydrology and its impact on the surface ecosystem. Because of this complexity, this indicator is limited to simply reporting on the quantities of surface water and groundwater with no attempt to establish the relationship that exists between them.

2.3. Monitoring the change relative to "natural" or "reference" conditions

The concept of a reference condition is well established in monitoring circles, having been adopted by agencies around the world for many years; indeed, it has been stated that unless there is a reference or target value, then an

TABLE 1. ECOSYSTEMS AND INDICATORS INCLUDED IN THIS METHOD

ECOSYSTEM CATEGORY	EXTENT INDICATORS
Vegetated wetlands (vegetation and water dominated ecosystems such as swamps, swamp forests, marshes, peatlands, paddies and mangroves)	▪ Spatial extent/area ▪ Water quality ▪ Wetland health indices
Inland open waters (lakes and artificial reservoirs)	▪ Spatial extent/area ▪ Quantity (volume) ▪ Water quality ▪ Ecosystem health or state
Rivers and estuaries (fresh and brackish)	▪ Quantity (streamflow) and environmental flows ▪ Water quality ▪ Biological or ecosystem health indices
Groundwater	▪ Quantity (depth to groundwater table) ▪ Water quality

indicator is not useful (Juwana et al. 2012). The European Water Framework Directive defines the reference condition for biological monitoring as "a description of the biological quality elements that exist, or would exist, at high status. That is, with no, or very minor disturbance from human activities. The objective of setting reference condition standards is to enable the assessment of ecological quality against these standards" (Water Framework Directive 2003). Stoddard et al. (2006) argue "the need for a *reference condition* term that is reserved for referring to the *naturalness* of the biota (structure and function) and that naturalness implies the absence of significant human disturbance or alteration". This approach is based on the somewhat broad assumption that a natural ecosystem has the greatest potential to provide ecosystem services including water services. The EU Water Framework Directive approach produces an Ecological Quality Ratio (EQR) which expresses the relationship between observed and reference condition values. Its numerical value lies between 0 and 1. The approach adopted for the SDG 6.6.1 indicator is similar, but uses a percentage rather than a ratio.

The reference condition approach however does have its limitations. One of the major challenges has been to find common approaches for defining reference conditions and the level of anthropogenic intervention allowed in reference sites (Pardo et al. 2012). That ecosystems change naturally over time in response to several drivers, and that to fix any one point as the reference condition is perhaps misleading are well known. However, for this SDG 6.6.1 indicator method, a fixed reference point, which could be adjusted in the long term following the acquisition of improved knowledge, is necessary in order to evaluate the magnitude and direction of change over time. After all, the SDGs are about long-term sustainability, so the best measure is the long term, and pre-development would be the best reference. Selection of the reference condition for a global assessment demands that a common point of reference should be used for every country. What better common point than the time before developments started, i.e., the Natural Reference? This puts every country on to the same scale, to monitor the change in their ecosystem from the time before change started (discounting natural changes which are generally far slower than those precipitated by human development). There will however be countries where development and ecosystem change has been taking place for so long that to set a pre-development Natural Reference may seem either impossible or not relevant. In many cases, actual data will not be available, and yet a Natural Reference can be "constructed" by using data collected from similar ecosystems (in the same ecoregion) that are in pristine condition, or by using historical reports and datasets or even just by using expert judgement. In this way the WFD (Water Framework Directive 2003) adopts a hierarchical approach for defining reference conditions as follows, considering only one of the following alternatives:

- An existing undisturbed site or a site with only very minor disturbance
- Historical data and information
- Models
- Expert judgement

Note: There is one major aspect of this indicator method where a natural reference may be difficult to establish, and that is for estimating change in the spatial extent of vegetated wetlands. There are classic examples like England where large wetlands were drained hundreds of years ago. Developing a true natural reference condition for such a country would be extremely difficult, although not impossible, by making use of seed and pollen banks in the sediments. Thus for monitoring the spatial extent of vegetation-dominated wetlands, a more recent reference condition could be more appropriate as described below (the "SDG baseline reference").

2.4. Recommended use of a reference condition for indicator 6.6.1

See Table 2 for a summary of reference conditions for indicator 6.6.1.

- *A "Natural" Reference condition* - The "minimally disturbed condition" from a time before large-scale impacts were imposed on a system. The natural condition however will still be subject to variability in terms of season and climatic variation so it is ideally determined according to a standard statistic, e.g., the mean extent over a number of "natural years". Where real data are not available to describe the natural reference, then a combination of extrapolation of data from near pristine sites, historical data, models and expert judgement can be used to construct a reference condition. Comparison of the observed present condition with this natural reference provides the best and most complete indication of change over time and is the recommended reference for this indicator. *This is the general standard for SDG reporting.*
- *A "Historical Reference" condition* - using historical data from a time when impacts on the ecosystem were less than the present situation. *This should only be used for SDG reporting where the Natural Reference cannot be estimated and should be indicated as such.* This reference is also appropriate for use by countries, where the earliest records could be used independently to set a Historical Reference condition that would be useful for more detailed management purposes. For example, some countries have aerial photographs and other datasets going back to the early 1900s that can be used to establish an accurate reference condition even though this may not be entirely natural. As technology advances, EO data could also be used to create a global database as a historical reference date with an earlier date.
- *"SDG Baseline Reference" condition* - This makes use of the first survey for SDG purposes carried out in 2017 or

TABLE 2. GUIDELINE FOR CHOOSING A REFERENCE CONDITION FOR REPORTING THE PRESENT DAY CONDITION

REFERENCE TYPE	MEASUREMENT OF CHANGE FROM	COMMENT	FOR USE
Natural Reference	Change from pre-development to observed present day	This provides the best result as it documents the total change over time. For some ecosystems, a true natural reference may be difficult to determine and thus may not be realistic	This is the standard for national and global SDG reporting, with the exception of spatial extent
Historic Reference	Change from a Historic Reference date where there are good data to the observed present day data	Use of historic data as a reference may be more robust and meaningful than the Natural Reference and may allow for more accurate measurement of change, over a reasonable time frame	National SDG reporting where a good historical dataset is the most reliable, or Global SDG reporting when agreed to by all countries (e.g., a fixed reference year based on a global dataset)
SDG Baseline Reference	Change from the beginning of SDG monitoring in 2017 to the future "present day"	This uses data from the first years of SDG reporting post-2017 and will only become a valid reference to monitor change over time later during Agenda 2030 and beyond	This should only be used where either the natural or historic reference is obtainable and must be indicated as such. This was the default reference condition for 2017 reporting.

soon after, which forms the baseline dataset against which all future monitoring will be compared and is the minimum requirement for this indicator but must be clearly indicated. Clearly, this reference will overlook any degradation that has taken place historically. *This is the interim reference condition for SDG reporting on spatial extent, which synchronizes with the approach of the Ramsar Convention on wetlands.* Over time a Baseline Reference will begin to gain relevance and will develop into an objective measure of change *from* the start of the SDG program in 2017.

2.5. Calculation of the percentage change

The 6.6.1 indicator requires that all data are reported as "the change [in extent] over time". This applies to spatial extent, quantity, quality and ecosystem health. In order to make comparable the different sub-indicator methods that are used, each of the results is assessed as the *percentage* change over time, when compared against the reference condition (see section above). The percentage change of each sub-indicator needs to be calculated separately before aggregation into the 6.6.1 score.

Thus, even where different approaches to a sub-indicator are used to calculate the score, the final results must be comparable. However, *careful interpretation is always needed* as the significance of a particular percentage change for each indicator may not be the same. Thus for example, a 50% increase in the depth to the groundwater may be insignificant if the original depth was only 3 m, but it presents a real challenge if the original depth was 50 m. Likewise, a 50% change in the spatial extent of wetlands in a basin would be far more serious than a 50% increase in phosphorous concentrations when these are at near pristine levels.

Percentage of change is calculated for each sub-indicator (*i*) as follows:

$$C\%i = (CPD/R)*100 \qquad [1]$$

$$CPD = |R - PD| \qquad [2]$$

where, *C%* = Percentage change of the Present-Day condition score from the Reference condition for sub-indicator *i*. *CPD* = Change of Present Day condition score from the Reference condition. *R* = Sub-indicator score set for the Reference condition (section 2.4). *PD* = Sub-indicator score obtained for the Present-Day condition.

2.6. Calculation of the Combined 6.6.1 Indicator Score

There is a single indicator for Target 6.6, which is described as the "Change in the extent of water-related ecosystems over time" and thus only a single quantitative measure should be used to identify the status of this Target at a sub-national, national and global level. However, this indicator has several sub-indicators that may include different ecosystems as well as different measures of the extent and health of those ecosystems, all of which need to be included as the information is useful especially at the local level (Figure 5). Thus, while for global reporting it may be necessary to aggregate the data from the sub-indicators into a single figure, at the national level management responses should be based on the separate sub-indicators which provide more meaningful information for water-related ecosystem management.

The aggregation of results into a single figure is inevitably problematic as the final result may hide a number of important results that would otherwise be clearly evident. For example, one of the sub-indicators may be in a critically poor state, yet the averaging effect of the other sub-indicators may mask this result and hence warning about this critical state could go unnoticed. Also, in certain parts of the world, some

Limitation of the 2017 reporting period

The sub-indicator of 6.6.1 will not produce a percentage of change estimate in 2017 because the data collected in 2017 will form the baseline reference condition. Calculations of the percentage of change will only be possible in the future. Country reporting in 2017 will thus be the baseline reference only. Countries are however encouraged to begin collection of reference condition data and to internally use the percentage change estimation indicated below.

FIGURE 5. EXAMPLE AGGREGATION OF SUB-INDICATOR DATA INTO THE 6.6.1 SCORE.

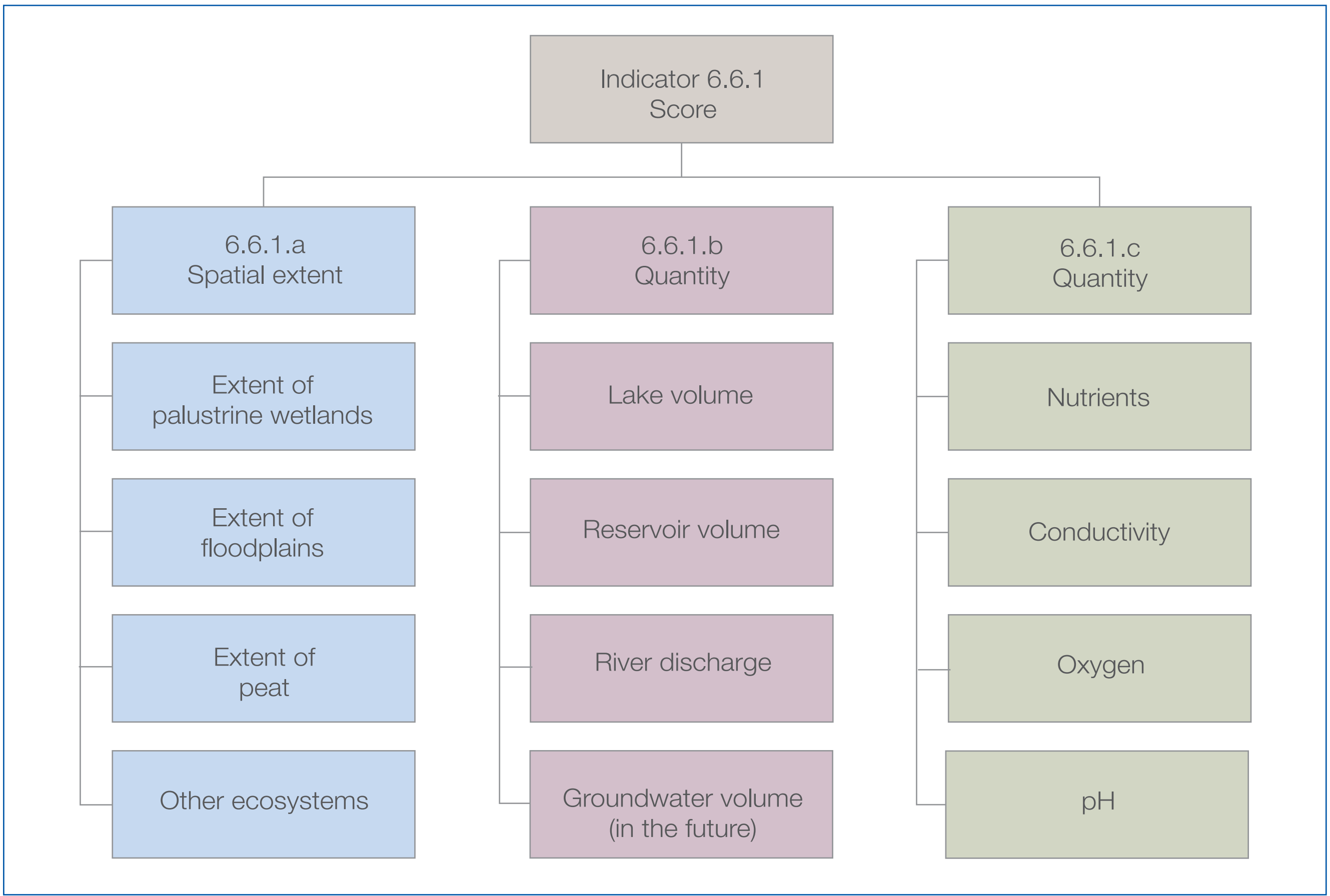
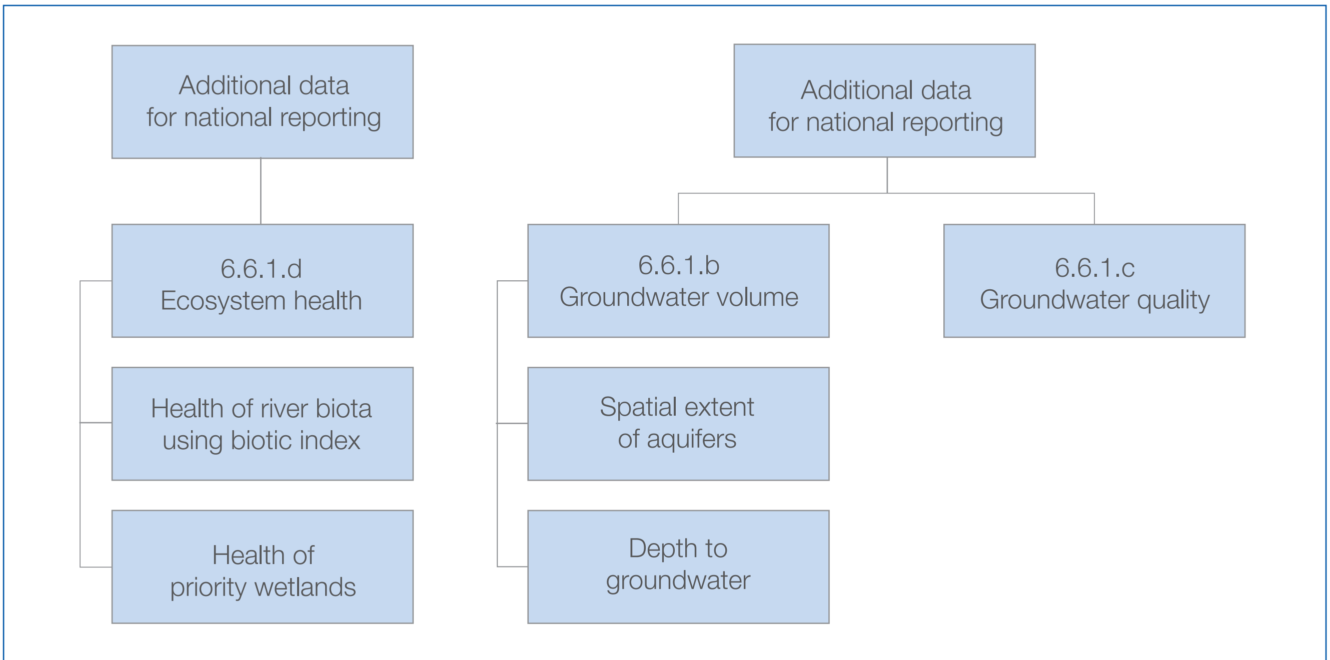


FIGURE 6. EXAMPLE SHOWING ADDITIONAL DATA COLLECTED AT NATIONAL LEVEL BUT NOT INCLUDED IN THE 6.6.1 COMPUTATION FOR THE 2017 SUBMISSION BUT WHICH MAY BE INCLUDED AT A LATER DATE. THESE ADDITIONAL DATA PROVIDE AN IMPORTANT PERSPECTIVE AT A NATIONAL LEVEL TO ASSIST WITH ECOSYSTEM MANAGEMENT.



of the sub-indicators may be important while others are not, but this nuance would be lost through aggregation. In the situation where corrective actions are being implemented, one sub-indicator may improve, whilst another continues deteriorating, giving a false impression of stability. Table 3 provides a hypothetical example of how the data for each sub-indicator are used to calculate the overall 6.6.1 score. Note however, that this was not done for the 2017 reporting period as no reference conditions were expected and thus the indicator score could not be calculated.

Table 3. Example calculation of the mean score for indicator 6.6.1 incorporating results of various sub-indicators (using fictitious data in this example). (Even though the numerical change in this example has become larger, the percentage change still represents a decline in ecological condition). Note that no weighting has been used in this example.

2.6.1. Weighting of sub-indicator scores

To overcome this tendency to hide important information during aggregation, using a weighting system -- where the different indicators are treated differently and those of greater importance are given greater weight -- is normally suggested. A comprehensive review of weighting of sustainability indicators is provided by Juwana et al. (2012). According to Nardo et al. (2005) this weighting can be done using expert judgement or via statistical methods. Sullivan et al. (2006) were of the view that this is best left to local decision makers and is not appropriate for researchers working at a distance. In the case of the Canadian Water Sustainability Index (CWSI); Policy Research Initiative (PRI), and the Watershed Sustainability Index (WSI); Chaves and Alipaz 2007 equal weighting was used for the sub-indicators with the opportunity for local stakeholders to apply weighting for their own purposes. For the West Java Water Sustainability Index (WJWSI), Juwana et al. 2010 both equal and non-equal weightings were investigated but were found to have no significant effect on the final index value (Juwana et al. 2011).

Weighting is risky when used for a global initiative such as the SDGs as it can be subjective, introduce bias and can engender distrust in the result. So, for the purposes of global reporting, all indicators and sub-indicators are given equal weighting (see Table 3). These weightings can however be changed at the national level for national-level management of water-related ecosystems. Expert judgement is recommended to be used here when required.

2.6.2. Aggregation of sub-indicator scores

While there are different accepted methods for aggregation of data such as the arithmetical and geometrical approaches, the arithmetical approach is applied to well-known sustainability indicators such as CWSI, WPI and WSI (Sullivan 2002; Chaves and Alipaz 2007; Policy Research. The formula used is the summation of weighted sub-index values as described by Nardo et al. (2005– see the formula below). However, based on the precedent set by the likes of sustainability indicators already using the arithmetical approach (CWSI, WPI and WSI), for the SDG 6.6.1 indicator method, equal weighting is recommended to be applied while using the arithmetical aggregation approach, which is then averaged as a different number of sub-indicators will be used at different locations. It is however possible that weighting can be adjusted for national-level use by using expert judgement that involves water resources decision makers. The relevant formula is presented below:

$$C\% = \left(\sum_{i=1}^{n} wi\ Si\right)/n$$

where, $C\%$ represents the mean aggregated percentage change of all sub-indicators, n is the number of sub-indicators to be aggregated, S_i is the sub-indicator for

TABLE 3. EXAMPLE CALCULATION OF THE MEAN SCORE FOR INDICATOR 6.6.1 INCORPORATING RESULTS OF VARIOUS SUB-INDICATORS (USING FICTITIOUS DATA IN THIS EXAMPLE). (EVEN THOUGH THE NUMERICAL CHANGE IN THIS EXAMPLE HAS BECOME LARGER, THE PERCENTAGE CHANGE STILL REPRESENTS A DECLINE IN ECOLOGICAL CONDITION). NOTE THAT NO WEIGHTING HAS BEEN USED IN THIS EXAMPLE.

SUB-INDICATOR	SUB-INDICATOR COMPONENTS (FOR EXAMPLE)	REF. VAL.	PRES. DAY VAL.	CHANGE OVER TIME	PERCENTAGE CHANGE	PERCENTAGE CHANGE OF SUB-INDIC. OVER TIME
Change in the spatial extent of water-related ecosystems	Change in extent of palustrine wetlands	656 km^2	439 km^2	217 km^2	33	30.5
	Change in extent of floodplain wetlands	110 km^2	79 km^2	31 km^2	28	
Change in the quantity of water in water-related ecosystems	Change in river flow	108 Mm^3	93 Mm^3	15 Mm^3	14	8.5
	Change in lake volume	1121 Mm^3	1087 Mm^3	34 km^2	3	
Change in quality of water	Change in water quality index from Target 6.3.2	100	86.4	13.6	13.6	13.6
TOTAL change for 6.6.1						17.5

indicator *I*, and w_i is the weight of sub-indicator *i* (which is set to 1 as the default).

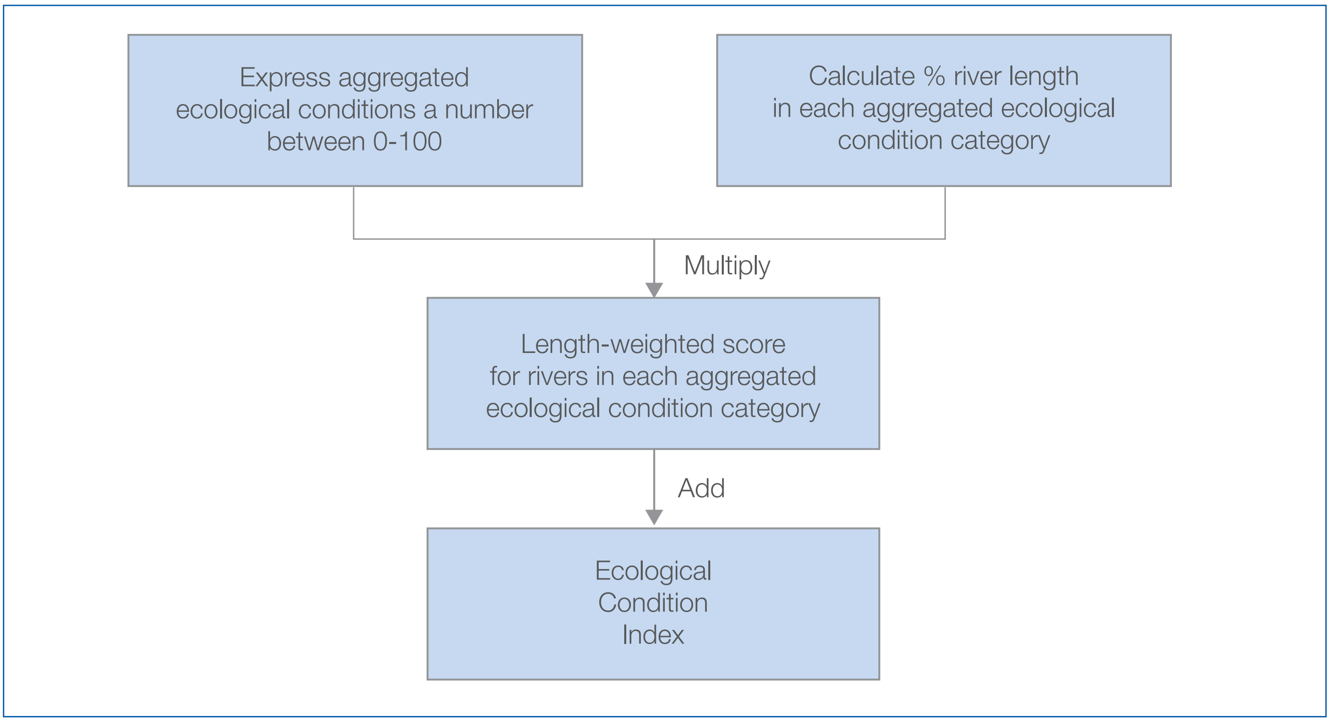
Note that the results of this calculation suggest that from a management perspective a score of 100% would be the most undesirable, showing a total loss of water-related ecosystems, and 0% would imply that no change from the reference had taken place from the natural situation.

An example of aggregation of river-health scores is to be found in Nel and Driver 2015 (2015) based on the global Experimental Ecosystem Accounting Project of UN Statistical Division (Figure 7), which illustrates their use of aggregation. They developed the Ecological Condition Index with very experienced stakeholders and gained the acceptance of these stakeholders that the index was worthwhile. They acknowledged that summarizing trends into a single index is generally easier to communicate than showing interrelated trends across several aggregated ecological condition categories. The index has been well received in South Africa where it is being used.

The SDG 6.6.1 indicator makes use of the arithmetic mean to combine all the sub-indicators into a single index score (see Figure 5, although remembering that the disaggregated data remains important and should always be accessible especially at a national scale).

NOTE that there is a risk that the real meaning of what the SDG 6.6.1 indicator should be revealing could be lost due to this process of integration, where important variables could be overshadowed by others. Again, it is important that countries maintain this data in a disaggregated form, so that in the future it will be possible for the country itself to interpret changes that are taking place but also so that in the future it may be possible, at a global level, to retroactively re-calculate a different form of the 6.6.1 indicator using the data collected from 2017 onwards.

FIGURE 7. THE SYSTEM FOLLOWED BY NEL AND DRIVER 2015 IN CONVERSION OF MULTIPLE SITE ASSESSMENTS AND SUMMARY DATA ON THE ECOLOGICAL CONDITION PRESENTED AT A QUINARY SCALE (SUB-QUATERNARY CATCHMENT LEVEL), INTO A SINGLE RESULT FOR A RIVER.



3. IMPLEMENTATION OF 6.6.1 MONITORING AT THE COUNTRY LEVEL

The GEMI (2017) have suggested that each country will decide on the scale and intensity of monitoring that will take place in that country, which will be defined by internal needs and capacity. A system of *Progressive Monitoring* has been suggested, where countries implement basic monitoring as a standard requirement, but add on progressively more monitoring as their needs and capacity increases. Thus, those sub-indicators with Priority 1 have been considered as the minimum required for SDG reporting, while others may be added depending on country needs. Note that only Priority 1 methods will be incorporated into the 6.6.1 score for the 2017 data collection however in future other methods will be included so countries are urged to progress with development and use of these methods at a national level. The proposed list of priorities is indicated in Table 4.

Table 4. The steps for progressive monitoring, indicating the order of priority for monitoring of the sub-indicators for 6.6.1. NOTE that 1 is high priority and 6 low priority. Only Step 1 forms part of the global report for 2017.

TABLE 4. THE STEPS FOR PROGRESSIVE MONITORING, INDICATING THE ORDER OF PRIORITY FOR MONITORING OF THE SUB-INDICATORS FOR 6.6.1.

STEPS	MONITORING ACTIVITY	DETAIL	UNITS OF MEASUREMENT
Step 1 represents the basic Indicator 6.6.1 used for Global Reporting			
1	Change in the spatial extent of surface water-related ecosystems	Each ecosystem type is assessed using a different method. Earth Observation methods are used where possible and require ground-based verification.	Percent change in area (km^2) from SDG baseline reference condition
1	Change in quantity of water stored in rivers and open water bodies	Change in the flow of rivers/estuaries, the volume of storage in lakes and artificial reservoirs.	Percent change in the mean annual volume of flow (Mm^3) from the natural reference condition. Percent change in volume (Mm^3) of water storage in lakes from the natural reference condition.
1	Change in quality of water in rivers and open water bodies	The quality of water in all ecosystems is a key driver of ecosystem change. This indicator is monitored as part of Target 6.3.2 and is linked here.	Percent change in water quality from the natural reference condition
The steps below are additional to the 6.6.1 basic indicator and are for reporting at a National level, not for Global Reporting.			
2	Ground based interpretation of ecosystem extent changes identified by EO	This activity adds value to the assessment of extent done in Step 1. Those water related ecosystem that are identified by EO to have significantly changed are assessed at ground level to determine the nature and cause of the change.	Percent change in area (km^2) from reference condition
3	Change in quality and quantity of groundwater aquifers	Quality and quantity characterize different aquifers and should be mapped. The quantity of water is represented by the depth to the groundwater table	Percent change in water quality and quantity from natural
4	Ground-based evaluation of ecosystem extent and also classification of wetland type	Delineation of ecosystem extent using ground-based survey. The advantage of this approach is that it allows classification of wetland type based on hydro-geomorphic or vegetation characteristics and assessment of the extent of wetland type. These techniques are used for priority ecosystems where more information is needed than can be provided by EO.	Percent change in area (km^2) from reference condition
5	Change in health or state of ecosystem health	Each ecosystem type is assessed using different methods e.g. benthic macroinvertebrates or fish in rivers or vegetation on a floodplain. Results need to be normalized as a percentage change from natural reference condition.	Percent change of biological indicator from natural reference condition

3.1. Criteria for selection of ecosystems and intensity of monitoring

During implementation of SDG 6.6.1 monitoring, important decisions will need to be made at the country level on just which ecosystems, and at what level of intensity, monitoring and reporting should be carried out. Clearly, this will have substantial consequences for the country given that data collection will be costly. It should be considered when making such decisions, that the purpose of SDG monitoring and reporting is primarily so that countries are enabled to improve management of their own resources. So, while national-scale reporting may be appropriate and useful for global SDG reporting, i.e., where the entire country is represented by a single figure for the 6.6.1 indicator, this resolution is of little value for country-level management. It is recommended that every country should evaluate the best possible resolution of monitoring considering both cost of implementation and local management needs. Basin-scale monitoring is of greater value for management, while sub-division of the basin into sub-basins and even ecosystems can be of even greater utility. This same data can then be aggregated into a single figure for global SDG reporting but the raw data should be kept in its disaggregated form for management purposes.

Thus the 6.6.1 method does not prescribe the intensity of monitoring or even which ecosystems are included in the monitoring effort. Such decisions are for countries to make, in keeping with internal management objectives but also in keeping with country obligations to the global SDG effort.

3.2. Setting a target for the 6.6.1 indicator

NOTE that targets for the 6.6.1 indicator are presented in Annex 1 of the official method document (GEMI 2017) and are not reproduced here.

The Agenda 2030 documentation (UN 2015)) gives little direction to the setting of targets or management objectives for each of the indicators, suggesting instead that this process should be carried out at the country level and should be unique for the management of resources in that country. However, it is important to appreciate the context of setting such targets, which in the case of this 6.6.1 Target is in relation to reference conditions.

It is important that the present-day condition compared to the reference condition is carefully interpreted, especially where this information is contributing to the setting of targets for management of the ecosystem. As described above, the natural reference condition is the preferred condition against which the present-day condition is observed for SDG reporting. The natural reference condition will, as the name suggests, reflects the ecosystem as it occurred before human impacts, which would include characteristics of both the structure and function of the ecosystem. However, this does not imply that the natural state would be the best state for a society to strive for as this would not allow for the development of society. So, while some departure from the natural reference is acceptable, it is incumbent on countries to make the decisions as to what degree the deviation from the reference condition is acceptable. Thus, the targets set by countries may not be the same as the reference condition but should be nevertheless considered sustainable by being not overly different from the natural reference, and also by being maintained on a level with, or on a positive (improving), trajectory.

It has been stated that unless there is a target value for management, then an indicator is not useful (Juwana et al. 2012). Thus, monitoring of ecological data provides data that, unless tied into management objectives, serve little purpose. An example that has been taken up as a national procedure in South Africa for setting water resources objectives is described in Dickens et al. (2011). This procedure requires a mix of scientific evidence, together with societal needs, where ultimately society must decide on the level of protection, or the risk of system failure, that it is prepared to accept. The role of the scientist is to provide evidence on the *status quo* which includes not only an indication of the state of the ecosystem, but also the risk of failure of the provision of services that matches the *status quo*.

The determination of targets for management of natural resources thus needs to be based on societal needs, but should be tempered by evidence provided by science. As a global context setter related to ecosystems and sustainability, the Convention of Biological Diversity (CBD) (Topfer 2000) stated that natural resources are not infinite and went ahead to set out a philosophy for sustainable use. The Convention states that past conservation efforts were aimed at protecting particular species and habitats, and recognizes that while ecosystems, species and genes must be used for the benefit of humans, this should be done in a way and at a rate that does not lead to the long-term decline of biological diversity (Topfer 2000). According to Agenda 21, biological resources constitute a capital asset with great potential for yielding sustainable benefits. *"Urgent and decisive action is needed to conserve and maintain genes, species and ecosystems, with a view to the sustainable management and use of biological resources"* (Agenda 21, UNEP, Conservation of Biological Diversity). Thus, conditions that depart from the natural (reference) condition imply that an ecosystem is at risk, although this risk may be within the acceptable management practice of a society. The Society for Ecological Restoration (SER) continued in this way by stating that a *"restored ecosystem contains a characteristic assemblage of the species that occur in the reference ecosystem and that provide appropriate community structure. The restored ecosystem is self-sustaining to the same degree as its reference ecosystem, and has the potential to persist indefinitely"* (Clewell et al. 2004).

When planning the development or alteration of any resource, it is generally the situation that limited use will have no impact on the sustainability of that resource; however with increasing use, the risks to sustainability are increased. This may reach a point where it can be considered that the use has exceeded sustainable use and where rehabilitation is now necessary. These are the Thresholds which are often used to set boundaries for resources management and which were so well documented by Biggs and Rogers (2003) and Rogers et al. (2013). They defined these thresholds as "a multidimensional envelope within which the variation of the ecosystem is acceptable to both scientists and managers." Kate Raworth (2012) offers an elegant solution through her notion of Doughnut Economics where the doughnut is the 'safe and just space for humanity' where she combines the seminal idea of Planetary Boundaries (Rockström et al. 2009) with new social boundaries. All these approaches are based on a "natural" condition of the ecosystem and discuss the issues associated with departure from this condition. Rates of movement towards or away from these thresholds give an indication of how the ecosystem is tracking in relation to its resilient characteristics and undesirable change. In parallel, the Ramsar Convention on wetlands, under Article 3.2 of the Convention notes that there should be notification of a change in ecological character as a result of modification (Ramsar Convention Secretariat 2010) and they introduce a term LAC (limits of acceptable change or more recently limits for defining change in ecological character - Ramsar Convention Secretariat 2011) to define the thresholds that are considered acceptable.

Some situations of ecosystem alteration, whether considered "good or bad", are difficult to interpret. For example, low to moderate levels of nutrient pollution in a lake may increase its productivity which is good for the provision of fish for society and may do the ecosystem no apparent harm, yet if concentrations increase beyond a certain level, then the ecosystem may change to a toxic and unacceptable condition. The question is, at what point is this change in nutrients considered as a move towards a less sustainable condition? Examples such as this often have a human needs interpretation, often a short-term one, which may not be sustainable in the longer term; thus in the above example, an assumption is made that the increased fish populations resulting from small amounts of nutrient addition are not harmful to the ecosystem. However, if the ecosystem was considered holistically, not just from the point of view of the economically related fish species, it may be found to be detrimental. It is thus necessary for long-term sustainability, that a long-term and holistic view of acceptable change is taken. The assumption can however be made, that any departure from that envelope of variation of the ecosystem that qualifies as the natural condition, represents an increased risk to the sustainable management and use of ecosystem resources. It is the level of risk that needs to be considered and managed by society. This is what needs to be taken on by each country in its own way. A possible approach is presented below, but it must be stated that this is one of many similar approaches.

A simple way of considering observed ecosystem data relative to the natural reference condition (see definitions above) is shown in Table 5. Each method, each sub-indicator, and indeed the overall 6.6.1 indicator, can be considered in terms of an Ecological Class, which describes the extent of deviation from the natural reference condition and which in turn can be considered in terms of the implications for the sustainable use of that ecosystem. These categories and the divisions between them are purely subjective, but provide an aid to management. For management to set a target category for a water resource, this may be done in different ways, ranging from simple social and political decisions linked to the vision for the resource, or it may be done using evidence derived from the ecosystem itself in a more complex process of modeling the likely outcomes. Thus, these Ecological Classes can be used to set targets, e.g., a catchment management agency may prescribe that a particular river flow should be in a B Ecological Category to sustain necessary ecosystem services to society.

3.3. Sub-Indicators for Target 6.6.1

Methods for determining each of the four sub-indicators are proposed below. Each sub-indicator reports a different but complementary aspect of the Target 6.6.1 indicator. Each sub-indicator is considered, as far as possible, in relation to the following aspects:

- Scope: Description of what is included in the particular sub-indicator, what aspects of Target 6.6 it covers, and what are not covered.
- Source of data: An indication of where the data will come from, which includes both EO and ground-based sources.
- Collection of data: Deals with gathering the data and provides an indication of the associated complexities.
- Representation of the data and the results calculated: The standardized way that data will need to be analyzed

TABLE 5. ECOLOGICAL CLASSES THAT SHOW THE RELATION OF THE ECOSYSTEM TO ITS NATURAL CONDITION (*SEE SECTIONS ABOVE FOR A DESCRIPTION OF THE NATURAL REFERENCE CONDITION). THESE ECOLOGICAL CLASSES CAN BE APPLIED TO ANY ASSESSMENT METHOD USED FOR THIS 6.6.1 INDICATOR, AND TO THE AGGREGATED 6.6.1 RESULT (BASED ON THE METHOD OF KLEYNHANS AND LOUW 2008).

ECOLOGICAL CATEGORY	DESCRIPTION	DEVIATION FROM NATURAL*	SUSTAINABILITY
A	Unmodified natural	0-10%	Highly sustainable
B	Largely natural with insignificant changes to the ecosystem.	11-20%	Highly sustainable
C	Moderately modified. Loss and change of natural habitat and biota have occurred but the basic ecosystem functions are unchanged.	21-40%	Locally sustainable but threatens global stability
D	Largely modified. A large change to habitat, biota and ecosystem functions has occurred. The ecosystem continues to provide services of value but is no longer representative of the natural situation.	41-60%	Border-line sustainability. Corrective actions are strongly recommended
E	Seriously modified. The loss of habitat, biota and ecosystem function is extensive and most services are lost to society.	61-100%	Unsustainable. Urgent renewal is required

Note: This ecological classification has been widely used in management of water resources in South Africa, e.g., Dickens et al. (2014) where these Classes (called Categories) are written as Resource Quality Objectives into regulations for a river basin management and where they are used for State of Rivers reporting http://www.dwaf.gov.za/iwqs/rhp/state_of_rivers.aspx.

to allow global comparisons and to address Target 6.6.

- Interpretation of results: Summary of the vast amounts of data that will be collected into a format suitable for SDG monitoring (and reporting). A description of the type of information that can be gained from the data.
- Setting targets: Setting of targets remains the responsibility of each country but some perspectives are given here.
- Quality control and sources of error.

3.4. National and global reporting of Target 6.6 data

In most countries the data and expertise necessary to collect all of the data required for reporting on Indicator 6.6.1 is distributed widely between different authorities and agencies. However UN Environment, as the custodian agency for this Indicator, prefers to communicate through a single focal point who is responsible for collating and reporting the data on behalf of his/her country. This focal point person need to be given the necessary authority by the country so that when the final report is submitted, then that report represents the official report of the country. Internally there are often parallel processes, where the national statistical office also have authority at a wider level, often reporting on all or many of the SDG targets. Internal arrangements for how the report should eventually be submitted, will differ from country to country.

The focal point person should expressly consult with the full range of appropriate organizations. These would probably include Ministries or Departments of:

- Water Resources (volumes, flows, water quality, ecosystem health)
- Hydrology / Hydropower (volumes, flows)
- Environment (spatial extent especially of wetlands, ecosystem health)
- And any other official agency with the necessary mandate.

The focal point should also consult with non-governmental agencies that have useful data, thus the RAMSAR Convention on Wetlands, World Wildlife Fund, IUCN and many others.

Reporting the data has been standardized globally as a necessary part of being able to synthesize and interpret the large amounts of global data that will be collected. The reporting form collects only the final results and does not require that the actual data used to measure the Indicator is reported. The reasons for this are twofold: sovereignty of the data, and because management of such large amounts of data would be onerous for the custodian agency.

A standardized, Excel spreadsheet/workbook has been designed by UN Environment for collection of 2017 national-level data for indicators 6.3.2 and 6.6.1 and it is to be submitted as the country report to the UN (Download the indicator method and the reporting form at http://www.sdg6monitoring.org). A Help Desk is also available using the following email address: SDG6waterquality.ecosystems@unep.org.

The reporting form or spreadsheet is largely self-explanatory and provides directions to its use on the first page, but some pointers to its use are provided here. Note that the single workbook includes both the 6.3.2 indicator on water quality and the 6.6.1 indicator on ecosystems. Because these two are included together, the importation of the water-quality data that form sub-indicator 6.1.1.c is automated. Note also that this reporting template captures only the final results of the 6.3.2 and 6.6.1 data collection and NOT the actual raw data (e.g., water-quality results, wetland inventories, etc.). Countries need to develop their own means to collect, sort and calculate the respective scores, which will be uniquely based on the design of the Country internal databases.

It is important at the outset to appreciate that this Excel spreadsheet/workbook was designed for use during the first data-drive in 2017. Because it is acknowledged that most countries will not be able to report on the actual change in extent required by the 6.6.1 method, mostly because they do not have reference data available, the spreadsheet is limited to collection of extent data only and has NOT included a space for the reference condition. This will be added in subsequent reporting periods. Thus, the extent is measured as km^2 for spatial extent and million m^3 (Mm^3) for volume of water (for rivers this is Mm^3/annum); water quality is measured at percentage change from the target value.

The spreadsheet is set up so that many of the component sheets are interconnected so it is important to follow the Overview that is on the first sheet and to adhere to the process of completing the data entry. The subsequent sheets have a list of definitions and a further list of data descriptors.

The fourth sheet is the first that requires entry of information, in this case the name and address of the person responsible for capturing the data. The fifth sheet is used for capture of the Reporting Basin District that needs to start with the two letters of the country ISO Country Code (that is obtainable from the last sheet). It is important that this code be entered here otherwise it does not activate the corresponding row in the other work sheets. Further identity of each Reporting Basin District is captured on this page, with a single row devoted to each subsequent District. Make use of the inserted comments to see further information on each column.

The sixth sheet opens with the linked Reporting Basin District codes so that a single row is used to capture the complete data for a Reporting Basin District. Firstly, the number of water bodies within the Reporting Basin District, and then the actual results of the water-quality assessment are obtained using the step-by-step method for indicator 6.3.2. This sheet also contains a record of the number of actual monitoring stations and the number of values used to calculate the score of water quality.

The seventh sheet again carries over the Reporting Basin District code and is followed by information that sets the water-quality targets for each variable monitored.

The eighth sheet combines the data from all the Reporting Basin Districts into a single indicator 6.3.2 result for each country.

The ninth sheet begins with indicator 6.6.1 data on the extent of water-related ecosystems. The Assessment Period is the time span used for each data estimate, thus for water quantity, the method recommends that a mean of the previous five years be used to smoothen short-term variation. The sheet captures results of the spatial extent (6.6.1.a) and water quantity (6.6.1.b) sub-indicators, while the water quality component (i.e. 6.6.1.c) is carried over automatically from the previous sheets where the 6.3.2 data on water quality were captured.

The tenth sheet combines the data from all the Reporting Basin Districts into a single indicator 6.6.1 result for each country. Note as indicated above, that for the 2017 reporting period there is no inclusion of reference data; thus the percentage change of ecosystem extent is not included in the report. This will be done for subsequent reporting periods.

3.5. Submission of national data

The responsible authority within each country reports the data for Indicators 6.3.2 and 6.6.1 together to UN Environment by sending the data to the following email address: SDG6waterquality.ecosystems@unep.org. It is important that internal agreement be reached between the National Statistical Office and the line ministries that collect these data, on how this submission should be made. A key issue is that there should be a focal point for each SDG indicator as well as for SDG reporting as a whole.

3.6. Obtaining further guidance for the implementation of this method

The step by step method for indicator 6.6.1 (GEMI 2017) and this guideline document contain an overview of the method for deriving each sub-indicator and are intended to point implementers in the direction of more detailed sources of information. Country implementers are expected to adopt approaches that are in keeping with their national situation, but within the confines of the methods described within this guideline. Further guidance is also available on the website www.sdg6monitoring.org where the above documents as well as webinar recordings and Power Point presentations disseminated during 2017 are available. UN Environment has also made available a help desk at SDG6waterquality.ecosystems@unep.org where individual queries can be addressed. Table 6 lists websites for water-related ecosystems data and guidance.

TABLE 6. INTERNATIONAL WEBSITES FOR WATER-RELATED ECOSYSTEMS DATA AND GUIDANCE (SEE LATER EO WEBSITES).

INVENTORY	SOURCE	WHAT IS IN IT?
RAMSAR Convention on Wetlands	http://ramsar.org	▪ Database on wetlands - https://rsis.ramsar.org/ ▪ Guidelines (including monitoring) - http://www.ramsar.org/resources/ramsar-handbooks-and-manual
Asian Wetland Inventory	https://www.wetlands.org/download/4437/	▪ Guidelines for the assessment, evaluation and monitoring of wetlands in Asia
Aquastat – water quantity	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en	▪ Water quantity database – surface water and groundwater water inflow and outflow of the country
Water Sanitation Health – water quality	▪ http://www.unep.org/gemswater/Portals/24154/pdfs/quality_control/Analytical%20Methods-GEMS-2014.pdf	▪ Relevant for indicator 6.3.2 ▪ Water quality monitoring guideline of freshwater - http://apps.who.int/iris/bitstream/10665/41851/1/0419217304_eng.pdf?ua=1 (describes water quality field- testing methods, sampling, design monitoring programme, chemical analysis, etc.). Note: a A few of these methods are also described in the draft concept of indicator 6.3.2. ▪ Water-quality assessment techniques – for rivers, lakes, reservoirs, and groundwater - http://apps.who.int/iris/bitstream/10665/41850/1/0419216006_eng.pdf
Global lakes and wetlands Database – water quantity	http://www.worldwildlife.org/pages/global-lakes-and-wetlands-database	▪ Database on spatial extent of lakes, rivers, reservoirs and different types of wetland types (GIS-based). It comprises the shoreline polygons of the 3067 largest lakes, the 654 largest reservoirs, permanent open water bodies and rivers.

CONTINUED

TABLE 6. INTERNATIONAL WEB SITES FOR WATER-RELATED ECOSYSTEMS DATA AND GUIDANCE (SEE LATER EO WEB SITES). *CONTINUED.*

INVENTORY	SOURCE	WHAT IS IN IT?
World Water Database – water quantity	http://www.waterdatabase.com/	▪ Quantitative data on: Large lakes size, average depth, maximum depth, surface elevation (and water volume)
Global surface water explorer	https://global-surface-water.appspot.com/	▪ Extent and change of water globally, making use of Landsat images as well as other sources of data.
UNEP – GEMStat/ Water – water quality	http://www.unep.org/gemswater/	▪ Contains info on water quality ▪ Measuring water quality of ecosystems – ▪ http://www.unep.org/gemswater/Portals/24154/pdfs/quality_control/Analytical%20Methods-GEMS-2014.pdf
Rivers and lakes and Hydroweb (from LEGOS) – water quantity	http://www.legos.obs-mip.fr/en/soa/hydrologie/hydroweb/	▪ Water quantity data – lakes http://www.legos.obs-mip.fr/soa/hydrologie/hydroweb/Objets.html ▪ Inland surface-water levels from satellite altimetry.
World water – water quantity	http://worldwater.org/water-data/	▪ Water quantity ▪ Total Renewable Freshwater Supply, by country ▪ Freshwater Withdrawal, by Country and Sector
Water footprint	http://waterfootprint.org/en/resources/water-footprint-statistics/	▪ Water pollution levels (per river basin)
Global runoff Data Centre – water quantity	http://www.bafg.de/GRDC/EN/02_srvcs/21_tmsrs/riverdischarge_node.html	▪ Water quantity. ▪ River discharge data
River flow models	WaterGAP2/3; CLM; DBH; DLEM; H08; JULES-TUC; JULES-UOE; LPJmL; Mac-PDM.09; MATSIRO; MPI-HM; ORCHIDEE; PCR-GLOBWB; SiBUC; SWBM; VIC	▪ WaterGAP2/3: can be used to compute water use and availability on basin level ▪ CLM (Community Land Model): Model to determine how climate is affected by human and natural changes in vegetation ▪ DBH (Distributed Biosphere-Hydrological model system): to compute the link of the hydrological cycle with the biosphere, climate system and human society. ▪ DLEM (Dynamic Land Ecosystem Model): Links hydrological, biophysical, biogeochemical processes, and vegetation dynamical and land use processes. ▪ H08: Global hydrological water model that includes human activities related to water use. ▪ JULES-TUC (Joint UK Land Environment Simulator): A land surface and atmosphere model that simulates fluxes of carbon, energy, and water. ▪ LPJmL (Lund-Potsdam-Jena managed Land): Simulates terrestrial water cycle, terrestrial carbon cycle and vegetation composition under climate change. ▪ Mac-PDM.09 (Macro scale Probability Distribution Model): Model to simulate runoff on a global scale. ▪ MATSIRO (Minimal Advanced Treatments of Surface Interaction and Runoff): Simulates processes of water and energy between land and atmosphere. ▪ MPI-HM (Max Planck Institute – Hydrological Model): Model on land surface and hydrological discharge ▪ ORCHIDEE (Organising Carbon and Hydrology in Dynamic Ecosystems): Computes land surface and atmospheric interaction in terms of water, energy and carbon. ▪ PCR-GLOBWB (PC Raster Global Water Balance): Simulates terrestrial hydrology. ▪ SiBUC (Simply Biosphere Urban Canopy): Simulates hydrological features in urban areas. ▪ SWBM (Spatial Water Budget Model): Simulates water supply and demand in the watershed. ▪ VIC model (Variable Infiltration Capacity): A grid-based macroscale hydrologic model which solves full water and energy balances.
UN-IGRAC – groundwater quantity and quality	http://www.un-igrac.org/global-groundwater-information-system-ggis	▪ Global groundwater data per country.
IWMI environmental flows – water quantity	http://gef.iwmi.org/ or http://waterdata.iwmi.org/Applications/Global_Assessment_Environmental_Water_Requirements_Scarcity/	▪ Contains a global assessment of environmental flows or water requirements used in SDG 6.4.2 as a low-confidence assessment of environmental flows.

A PALUSTRINE WETLAND IN THE OKAVANGO DELTA, BOTSWANA

Photo: Chris Dickens/IWMI

3.7. Sub-indicator 6.6.1.a: Spatial extent of water-related ecosystems

3.7.1. Scope

Before progressing with this sub-indicator, it is necessary to address the issue of definitions to avoid confusion with a similar and complimentary initiative being carried out by the Ramsar Convention on Wetlands. The Ramsar approach to collection of national wetland inventories provides an important source of data for SDG 6.6.1 and indeed the processes of the two should be intimately linked at the country level. However, the objectives of the two initiatives are different so that some caution needs to be exercised.

The definition of a wetland as used by Ramsar is *"areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters. It may also include subterranean hydrological systems[2]".* For indicator 6.6.1 a, because of the focus given to the SDG Goal 6 which is ensuring water for people, it is necessary to focus on inland freshwater ecosystems, although transition zones including estuaries and mangroves have also been included (see the definition of water-related ecosystems in the Introduction above). Thus, for indicator 6.6.1.a, which monitors the spatial extent of water-related ecosystems, the included ecosystems are vegetated wetlands (swamps, swamp forests, marshes, paddies, peatlands and mangroves), open water bodies (lakes and reservoirs), rivers and estuaries and groundwater aquifers.

The extent of water-related ecosystems may change either as a result of a reduction (or increase) of water inflows (to surface water and/or groundwater) due to upstream or local abstraction, or as a result of direct alteration of the habitat such as infilling or draining or removal of vegetation (e.g., cutting of mangroves and forests) or even as a result of change in direct precipitation and evaporation due to climate change. Tectonic processes also cause change in some areas. It should however be appreciated that not all water-related ecosystems will show a changed spatial extent following impact and even as a result of a reduction in water quantity. For example, rivers in narrow valleys do not change substantially in area or spatial extent as a result of loss of water.

The sub-indicator 6.6.1.a is intended to document the change in spatial extent of water-related ecosystems over time. It does not consider the condition of the ecosystem that has been subjected to changed extent, that being the subject of other sub-indicators.

[2] Definition from Ramsar Convention Article 1.1. In addition, the Ramsar Classification System for Wetland Type was approved by Recommendation 4.7 and amended by Resolution VI.5 of the Conference of the Contracting Parties which confirms the inclusion of subterranean hydrological systems within the definition.

As noted above, and championed by the very successful global effort of the Ramsar Convention of Wetlands, many countries and regions have their own wetland inventory or monitoring systems that give emphasis to monitoring the change in spatial extent. Examples include the U.S. Fish & Wildlife National Wetlands Inventory (Wilen and Bates 1995), the South African Wetlands Inventory (Ewart-Smith et al. 2006), and the South Australian Wetland Inventory Database (Taylor 2006). Such datasets provide a useful baseline and entry into reporting on SDG 6.6.1.a. although caution must be exercised to ensure that only the freshwater and brackish water ecosystems are included for 6.6.1.a reporting.

To measure changes in the spatial extent of water-related ecosystems, monitoring programs may include a range of techniques from ground-based assessments to the use of EO. However, the most important issue here is what constitutes the boundary of the water-related ecosystem that is being measured? The United States Department of Agriculture (USDA 2010) details a method for delineating wetlands by identifying hydric soils. Alternatively, vegetation density and type may be used to measure extent of wetlands at ground level – a method adopted by Kindscher et al. (1997) in their study of the wetlands of Grand Teton National Park. A variety of approaches to quantify wetland extent from EO data has been applied including orthophotography (Barrette et al. 2000), combined use of EO data and field assessments (Rebelo et al. 2009), data from radar systems such as RADARSAT (Ozesmi and Bauer 2002) and LiDAR imaging (Maxa and Bolstad 2009). The appropriate choice of method depends on factors such as the size of the wetland area (Mwita et al. 2012) and the characteristics of the vegetation cover (Fuller et al. 2006).

Currently, there is no globally standardized or accepted method for mapping or monitoring wetland extent. At the time of writing, Zheng et al. (2015) stated that existing global wetland maps were incomplete and data are often incomparable due to the use of inconsistent methods. To harmonize and provide consistent methods means also to use harmonized, standardized nomenclatures and approaches (or crosswalks) to ensure comparability between mapping locations and dates and provide a basis to upscale from local/national to regional and global statistics. The EU Horizon 2020 project SWOS (www.swos-service.eu) provides the first standards for mapping methods with hierarchical nomenclatures and crosswalks.
Regional-scale initiatives exist, such as the Mediterranean Wetlands Observatory which produces a range of indicators including the surface area of Mediterranean wetlands (Mediterranean Wetlands: Outlook 2012) and the GlobWetland projects (www.globwetland.org, http://globwetland-africa.org) – a joint undertaking between the European Space Agency (ESA) and the Ramsar Secretariat to survey and monitor wetland ecosystems using remote sensing techniques – yet these have not attempted to produce comprehensive or consistent assessments of global extent of wetlands (Zheng et al. 2015) but this can be anticipated to happen soon.

In order to achieve this, a standardized monitoring method is needed which can be implemented by individual countries and used to measure progress concerning the protection and restoration of wetland ecosystems. This report summarizes the options available.

A key player in this type of assessment, as already noted above, is the Ramsar Convention on Wetlands and the participating countries that are already sharing their data on the extent of wetlands. Congruency between the Fourth Ramsar Strategic Plan 2016-2024, the SDG 6.6.1 method and also the Aichi Biodiversity Targets is promoted by Ramsar. The Ramsar Strategic goal 2 Target 5 promotes the maintenance and restoration of the ecological character of Ramsar wetlands, which is thus in keeping with SDG 6.6.1. However, the indicators used by Ramsar are largely on management plans and communications material and fewer on the biophysical material as in the SDG approach. While Ramsar has indicated (pers. com.) that many countries have adopted a "no net loss" policy as a target, there is no requirement to do so in the Strategic Plan. A further congruency between Ramsar and the SDG 6.6.1 method is that in the National Reporting Framework of Ramsar, Question 8.6 asks "Based upon the National Wetland Inventory if available please provide a baseline figure in square kilometers for the extent of wetlands (according to the Ramsar definition) for the year 2017". SDG Target 6.6 does the same although eventually it will extend this to the percentage change over time.

Change in spatial extent – As noted earlier in the above description of Reference Condition, it has been agreed that 2017 will become the Baseline year against which the change in extent will be measured, but only in the future. Thus for 2017 only the net area in km^2 will be reported. In the future, it may be possible to produce a global image of the extent of the wetlands by using historical satellite pictures and from this to produce a historical reference condition of spatial extent, but this is not available at the time of publication.

3.7.2. Change in extent of vegetated wetlands (swamps, swamp forests, marshes, paddies, peatlands and mangroves)

Sub-indicator 6.6.1.a documents the change in extent of vegetated (palustrine) wetlands including marshes, bogs, and seeps as well as wetlands which have over the years built up quantities of peat and even includes artificial paddies. The word palustrine originates from the Latin *palus* which means "marsh" and is used to describe inland, non-tidal wetlands which are characterized by the presence of trees, shrubs and emergent vegetation. In some cases, the wetlands may be dry for periods of the year, and in others may be subject to permanent inundation, but the essential characteristic is that the wetlands are associated with vegetation that is dependent on inundation for at least part of the year. This hydrophilic vegetation provides one indication of the extent of the wetland, and may be combined with information on inundation by water and the associated chemical structure of the soil resulting from continued/frequent inundation in order to establish the boundaries of the wetland.

Palustrine wetlands have been particularly vulnerable to change by society and in many parts of the world conversion of these wetlands to terrestrial agricultural land has been actively promoted. Monitoring the change of extent of this ecosystem type is thus critical for informing progress towards achieving Target 6.6. One of the major challenges in monitoring these ecosystems is that many are hydrologically partially or totally isolated; thus a situation may arise where one wetland is seriously degraded, while an adjacent one may be in pristine condition. A further challenge is that these wetlands range in size from small seeps that may be only a few meters across, to wetlands thousands of square kilometers in extent (e.g., the Okavango, the Pantanal, and the Sudd).

Identification of vegetated or palustrine wetlands and subsequent monitoring of their extent can be achieved through combined use of EO data and ground-based assessments as will be shown later.

An important vegetated wetland type that has been singled out for monitoring are mangroves forests. Mangroves are important for the stability of many coastal areas and for the protection of communities against tidal surges and large waves. They do not have any link to the provision of water to society, but do provide abundant services to society. These ecosystems are often transition zones between freshwater and salt water and, in many cases, it would be impossible to consider a river ecosystem holistically without considering its estuary (and mangroves, if present). Mangroves are rich in biodiversity and also provide a wide range of other ecosystem services. Many mangroves have been cleared for a variety of reasons but more recently there are trends to reverse this.

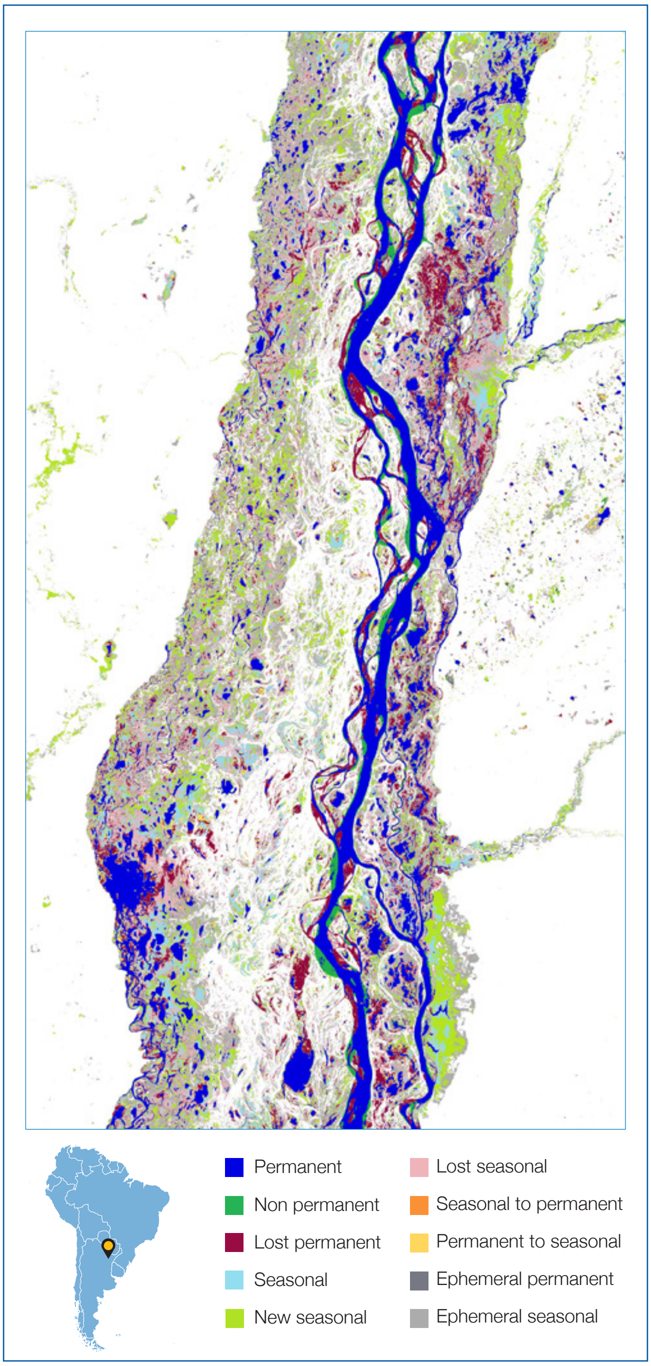
Changes in the spatial extent of mangroves can be detected using EO techniques supported by ground-based verification. In many cases, mangrove areas are relatively small and are, thus, amenable to ground-based surveys, while in some cases the use of drones or aerial surveys may be most effective. Earth Observation (EO) techniques (see below) are well developed for this purpose, with a global baseline derived from EO data available for 2000 (Giri et al. 2010.

3.7.3. Change in spatial extent of open water - ponds, lakes (lacustrine/ lentic wetlands) and reservoirs

The extent of ponds and lakes is generally affected by reductions in freshwater inflow, or by direct abstraction from the surface or even from nearby groundwater. Reduction in the volume of water in the ecosystem leads to reduction in spatial extent, as in the cases of Lake Chad and the Aral Sea (see the cover picture) which have received international attention. There are a large number of much smaller systems that have suffered a similar fate.

One of the challenges of monitoring open water bodies is that it includes constructed water bodies (dams, reservoirs).

FIGURE 8. AN EXAMPLE REPRODUCED FROM PEKEL ET AL. (2016) SHOWING CHANGES OVER TIME OF OPEN WATER: THE PARANA RIVER IN ARGENTINA.



High-resolution mapping of global surface water and its long-term changes. Jean-François Peke, Andrew Cottam, Noel Gorelick and Alan S. Belward. Nature 2016.

An excellent report that presents an overview of the status of global open water distribution and temporal change is to be found in this paper by Pekel et al. (2016). This paper makes use of a combination of three million Landsat images together with other sources of data to present a picture of the change in water over time, in this case over 32 years. An example of the change in water distribution over time is shown in Figure 8. The report contains fascinating insights into the distribution and changes of open surface water, and more importantly for this SDG monitoring, references useful sources of data that can be used. Key among these is the EU supported database (freely available from https://global-surface-water.appspot.com/). The report claims an accuracy of "less than 1% of false water detections, and misses less than 5% of water" and is a useful guide and resource for SDG monitoring. However, this report and the databases referred to therein, do not replace the need for country level SDG monitoring and reporting. At a country level, it will be possible to ground-truth and verify the data collected, and also to add in local understanding to produce data, again at a country level, that is more nuanced, accurate and also more valuable for country management of water resources. An important local adaptation is to select the statistic that best represents the long-term change in water distribution.

If possible, the data showing spatial extent of reservoirs should be kept separate as they are not part of the natural ecosystem but they do store large amounts of water and support altered ecosystems. Reservoirs are subject to continual alteration associated with their routine operation so that monitoring their change in extent can be challenging. It is important to keep the perspective that it is the long-term change in extent that is relevant, not the short-term operational changes to ensure that a suitable statistic is chosen to indicate the situation over several years (e.g., a rolling 5-year mean spatial extent).

This data on spatial extent are used directly to calculate open water volumes as part of indicator 6.6.1.b. Identification and monitoring of this group of water-related ecosystems can be achieved through the use of EO data, as the open water surface is easy to detect and measure.

3.7.4. Change in spatial extent of rivers and estuaries (lotic wetlands)

The change in spatial extent of rivers is most usually driven by a change in discharge (river flow), especially those rivers that traverse land with a minimal gradient and which tend to "spread out" over the land. However, where the river banks are steep, a change in discharge may result in only minor changes to spatial extent. The spatial extent of estuaries will be similarly affected by the steepness of the land.

Monitoring the change in spatial extent of many rivers and estuaries would thus be a futile exercise as changes would be insignificant and anyway the associated change in discharge will be captured by sub-indicator 6.6.1.b. Monitoring of those rivers which are meandering and wide, where reductions in flow would result in a significant change in extent, remains a possibility especially as the discharge of such rivers is often not adequately measured. However, it needs to be judged whether simply monitoring the discharge of a river would not be an easier form of monitoring to achieve the same goal. For this reason it is only recommended that monitoring of spatial extent of rivers and estuaries be done in special circumstances, which should be based on a country decision.

Monitoring is possible for larger systems using EO data combined with ground-based measurements. One challenge when monitoring spatial extent of estuaries is to delineate the downstream or marine extremity of an estuary. This extremity will change daily with tidal fluctuations but will similarly change over time as a result of changing freshwater inflows from upstream. There is no set "rule" for where this boundary should be set but, at a country level, cognizance should be given to this and a consistent approach followed.

3.7.5. Change in spatial or areal extent of groundwater

Monitoring the extent of groundwater is always a challenge given that the water is "out of sight". There are many different techniques which are used individually or in combination to map aquifers, from classical hydrogeological fieldwork, to interpreting pre-existing (hydro) geological maps, aerial photographs, satellite images, remote sensing, ground or airborne geophysics, etc. The choice of method to be used will depend on many factors that are not elaborated on here. Suffice to say that an estimation of the areal extent is a necessary part of quantifying the volume of groundwater as is described below for SDG 6.6.1.b.

3.7.6. Source and collection of data

This section describes approaches to data collection to determine the spatial extent of the water-related ecosystems. It is proposed to estimate the spatial extent of each major ecosystem present in a country using a mixture of ground data and EO assessment; various types of EO data are freely and globally available at no cost and can be used by national institutions for this purpose.

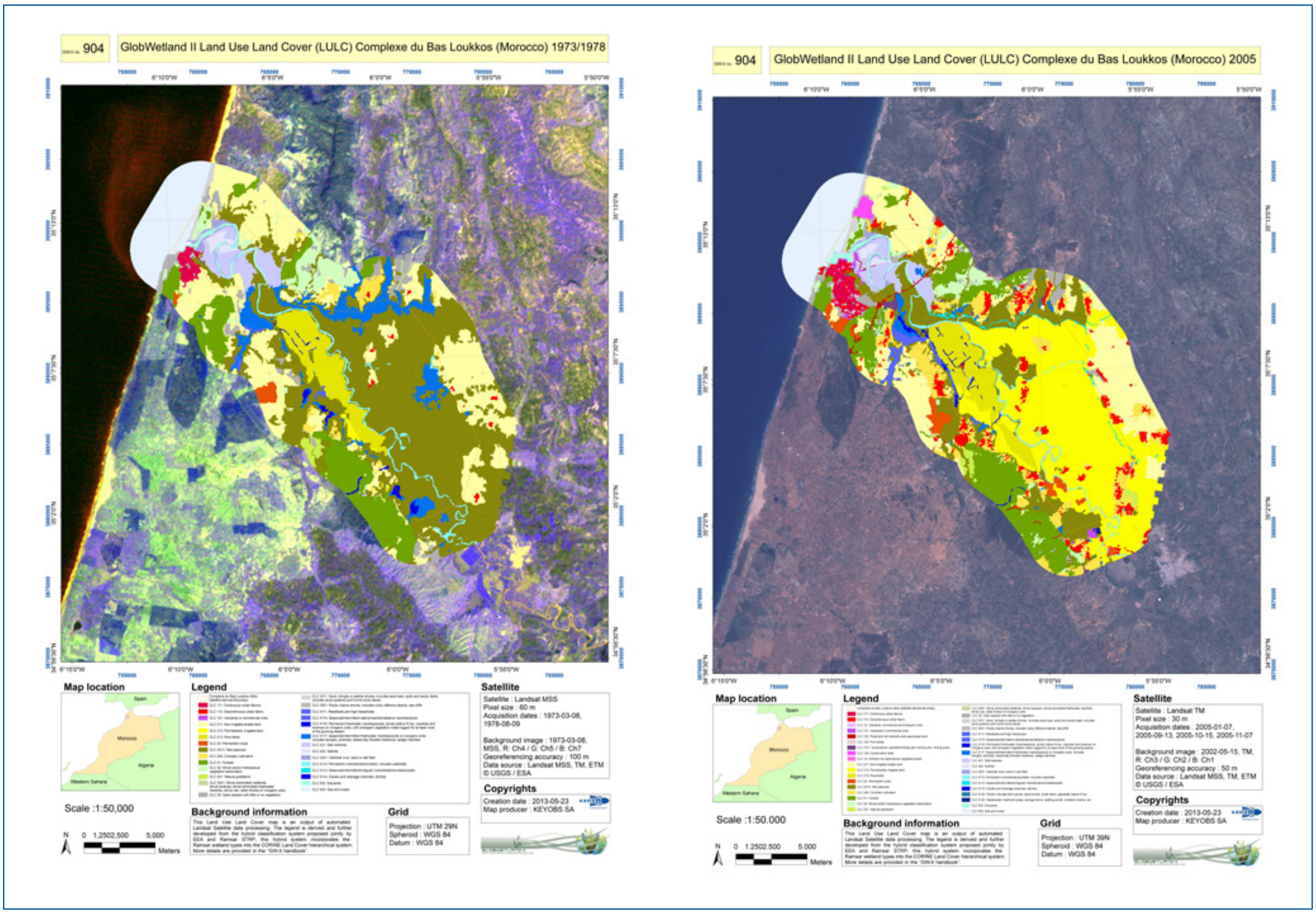
Because of the complexity in making use of EO data, some countries may choose to make use of global efforts to collect and process the data. The custodian agency of the 6.6.1 indicator method and data, UN Environment, will in future be in a position to assist with collection and interpretation of this data, on behalf of and with agreement by countries. Country ownership of the data remains important, hence such an assessment can only be done as a collaboration between the custodian and the participating country, which at time of submission should "sign off" the data as a true representation of its situation on spatial extent.

An alternative approach is to make use of one of the global EO initiatives, such as GlobWetlands and the Global Wetlands Observing System (GWOS), which provide invaluable starting points for the implementation of the SDGs for Target 6.6 (see the list below). These initiatives are well developed and provide an immediate entry point for organizations or countries wishing to collect data. GlobWetlands has a web portal from which many of the tools and assistance can be accessed and they have an excellent tutorial on how this may be done (http://globwetland-africa.org/wp-content/uploads/2017/03/GWA_ToolboxDemo_March2017.mp4). SWOS (Satellite-based Wetland Observation Service) also has a portal that can be used at http://portal.swos-service.eu. It should also be noted that varying levels of wetland-related information already exists for most countries which are signatories to the Ramsar Convention, but additional information may need to be collected to monitor other ecosystems or to align the Ramsar inventories with 6.6.1 requirements.

International initiatives that provide guidance on the use of EO for monitoring of water-related ecosystems:

- GlobWetland II – Initiated to assist with the establishment of a Global Wetland Observing System (GWOS) but also included the production of a number of wetland-related geo-information maps and indicators (http://www.globwetland.org/ and http://webgis.jena-optronik.de).
- GlobWetland Africa – A new project designed to demonstrate (using Africa as the pilot study) how to make the best use of satellite-based information on the extent of wetlands and condition for measuring the ecological state of wetlands and hence their capacity to support biodiversity and provide ecosystem services. One of the key deliverables under GlobWetland Africa will be the development of an open-source software toolbox with full end-to-end image-processing capabilities for producing large-scale inventories of the extent of wetlands needed by national agencies for their standard monitoring and reporting requirements, including those under Target 6.6. of the SDGs (www.globwetland-africa.org).
- *Satellite-based Wetland Observation Service (SWOS)* provides the tools and services for monitoring and assessment of wetland habitats, surface water dynamics, temperature, water quality, inventory and delineation. It also facilitates indicator computation, provides the infrastructure for the Global Wetland Observing System (GWOS) and connects various initiatives and projects as described on its web site (www.swos-service.eu). This site also provides standards for the delimitation of mapping areas and for nomenclatures and "crosswalks". Their portal for wetland monitoring is at http://portal.swos-service.eu. The GEOclassifier software (http://swos-service.eu/documents_mapping-software/), is a free and available toolbox for end to end satellite based wetland monitoring, and has been developed in the context of several projects like Globwetland II and SWOS and provides an object based mapping and indicator calculation approach with different standardized nomenclatures and corresponding "crosswalks".
- Global Mangrove Watch intends to help safeguard against mangrove forest degradation, by revealing the locations as well as the causes of mangrove degradation. This initiative aims to provide an assessment of changes in mangrove extent from the year 2000 (baseline) (http://www.eorc.jaxa.jp/ALOS/en/kyoto/mangrovewatch.htm).
- Mediterranean Wetlands Initiative and Its Mediterranean Wetlands Observatory set up to ensure the effective conservation of the functions and values of wetlands and the sustainable use of their resources and services, and monitor them, within the framework of the Ramsar Convention (http://medwet.org/; http://medwet.org/medwet/observatory/; http://www.medwetlands-obs.org/).
- GWOS (Global Wetlands Observing System) is a global initiative which collects information on the status and values of wetlands and water in a way that can support policy processes and decision making at various geographic scales; this will describe status and trends over time - http://geobon.org/global-wetlands-observing-system-gwos/ .
- Global System Water Project - GRaND (Global reservoir and dams with socio-economic data) that makes use of EO data - http://sedac.ciesin.columbia.edu/data/collection/grand-v1.
- Global Landcover (open water) Facility - http://glcf.umd.edu/data/watercover/.
- Global Surface Water Project maps surface waterbodies and estimates their changes over a 32-year period, based on Landsat imagery. https://global-surface-water.appspot.com/.
- Global Environmental Flow Requirements Data: http://waterdata.iwmi.org/Applications/Global_Assessment_Environmental_Water_Requirements_Scarcity/ or http://gef.iwmi.org/.
- http://www.glass-project.eu – Global Lakes Sentinel Services looking at water quality in rivers and lakes using EO.
- http://www.earth2observe.eu – for integrated water resource assessments that integrate EO data on groundwater, surface water, water quality, soil moisture, precipitation and evaporation.
- https://www.earthobservations.org – the Group on Earth Observations creating a Global Earth Observation System of Systems (GEOSS): Thus, this is an overarching facility with data of all types using their portal http://www.geoportal.org/.
- http://geobon.org – Group on Earth Observations targeting biodiversity and ecosystems.

FIGURE 9. EXAMPLE OF EO MONITORING OF THE CHANGE IN SPATIAL EXTENT FROM 1973 - 2005.



Note the change of "wet pasture" (olive color) to irrigated land (yellow color) and the reduction of "open water" (blue) to "wet pasture" (olive) and the increase in urban area (red). *Source:* Kathrin Weise, GlobWetland II

3.7.7. Earth Observation (EO)/Remote Sensing as a means of data collection

The international space agencies, such as NASA, JAXA and ESA have archived large quantities of data acquired by different sensors and at varying spatial and temporal resolutions. There is thus an almost bewildering amount and diversity of data and information so that it is, therefore, necessary to provide guidance on which type of EO data are appropriate. The SDG 6.6.1 method does not prescribe any particular approach as this field is advancing rapidly. It will be necessary during implementation to check on the latest available methods.

Satellite images which can be used to describe the location and spatial extent of most water-related ecosystems, which are available at spatial resolutions down to 10 m. Figure 9 gives an example of reporting using EO, in this case to show from 1973 to 2005 the change in spatial extent of waterbodies in Morocco. Earth Observation technology provides extensive data that can be used globally or at a national or subnational level. Several image archives are available to all users free of charge although the costs of data acquisition may be high at a national level in terms of time and data storage. There will also be costs associated with the interpretation of the data. In addition, ground-based verification of the results derived from the EO data are necessary to ensure valid results.

Various space-borne sensors have been launched in the recent past and most are designed for specific purposes; hence their images differ in terms of spectral and spatial resolution and revisit periods. The spatial resolution of the sensors determines the level of detail which can be identified and the spectral resolution of the wavelength characteristics (which enables different features of the Earth surface to be detected). All these contribute to the spatial coverage per image and generally the revisit time (i.e., the temporal resolution). Regardless of scale, the best results are typically acquired through analysis of multi-sensor (i.e., optical and radar) images in time series (to capture key ecosystem characteristics. The most relevant sensors for mapping at different scales are as follows (note that not all these data are available at no cost – see Tables 7-9 for more information):

- High resolution (10 – 30 m): Landsat TM/ETM/OLI, Sentinel SAR/MSI, ALOS Palsar, ENVISAT ASAR (2002-2012).
- Low resolution (300 m): ENVISAT MERIS/AATSR (2002-2012), MODIS, PROBA-V, VIIRS, SPOT VGT and Sentinel-3 (OLCI).

In many cases, the choice of mapping scale will be a question of cost-benefit. High spatial resolution mapping is costlier (as it requires more effort and data handling) than lower spatial resolution mapping but will also provide a greater level of detail. For certain dynamic features (e.g., floodplain extent) it may be better to use low-spatial but high temporal-resolution data to accurately capture the seasonal dynamics. The chosen satellite resolution, revisit time and the period over which images have been collected are crucial in choosing the most appropriate data to be used.

a. The spatial resolution of the data used to delineate ecosystems determines the quality of the product developed. For example, a wetland map produced using a 1-km resolution satellite image will be of poor quality (i.e., it will capture few details) as compared to one produced using a 30 m resolution satellite image.
b. The revisit period of a sensor over an area is important for identifying spatial changes. Monitoring a rapidly changing water surface area may require weekly or monthly revisit periods whereas an annual image may miss important changes.

Currently, there is no single approach which can be considered the best for mapping the extent of water-related ecosystems from EO data, and approaches used tend to vary according to objectives and scale of study, satellite data used and environmental settings. Nevertheless, there is a consensus that, where possible, inventories of these ecosystems should be carried out using a combination of multi-temporal optical- and radar-derived indicators, combining the advantages of both types of sensors.

It is also important to recognize that new EO capabilities will soon cause a paradigm shift in terms of securing robust and reliable long-term operational capacity that will support users for decades to come. For example, the Sentinel missions of the European Copernicus initiative will provide long-term access to enhanced high spatial resolution radar and optical observations making possible the systematic mapping, assessment and monitoring of water-related ecosystems worldwide:

- The C-band radar of the Sentinel 1 mission will provide all-weather and day-and-night imagery that will be extremely useful for monitoring ecosystems in cloudy conditions, and to follow the changes of surface waters.
- The footprint of Sentinel 2 (i.e., the geographic coverage of the images) along with its short revisit time and its systematic acquisition policy will allow rapid changes in ecosystems to be precisely monitored and is ideally suited to monitor sensitive habitats such as wetlands.
- The Sentinel 2 mission will ideally complement the longest continuously acquired collection of optical observations at high resolution made by the family of Landsat images (operational since 1972), which are freely accessible and offer a unique opportunity to assess the historical conditions of water-related ecosystems, worldwide.

The Copernicus (ESA) and the Landsat (NASA) data policies, with their full and open data access for all users worldwide, are important incentives that will facilitate the uptake of EO technologies for monitoring of SDG indicator 6.6.1. A critical presumption in this regard is the ability of users to access data and the necessary algorithms. It is widely recognized that the raw data required to produce national inventories can be challenging for many users to handle which is why there is an increased focus on the development of online platforms where users can process data before downloading the final result.

There are other localized sensors that have been launched by individual countries, for example, South Africa's Sumbandila Sat and India's IRS. While these are not considered of importance for global-scale projects, they do however provide valuable data at the national level for the relevant countries.

Various forthcoming or future satellite missions have either been designed for water-related ecosystem purposes or are suitable for such applications, such as the Soil Moisture Active Passive (SMAP) (launched in January 2015), and the Surface Water and Ocean Topography (SWOT), planned for 2019. These are expected to provide soil moisture and surface-water area at unprecedented spatial and temporal resolutions (Fluet-Chouinard et al. 2015). Sensors such as these may prove valuable additions to monitoring ecosystem extent. Table 7 lists agencies and satellites to determine the extent of water-related ecosystems.

Table 8 gives a summary of remote sensors applicable to monitoring the extent of water-related ecosystem.

Table 9 considers the use of different types of EO data suitable for monitoring a range of ecosystem types. It may be necessary to use different types of data acquired by different sensors to characterize the various ecosystems; sensors which provide data suitable for assessing palustrine or forested wetlands are not, for example, the same as those suitable for determining extent of open water bodies.

Table 9 documents the EO approaches available for assessment of water-related ecosystems but does not include more traditional approaches such as the use of aerial photographs (Figure 10), which can provide a valuable resource that, in some locations, extends back to the early part of the twentieth century and thus provides a record to assist with the determination of the Natural Reference condition. These records provide information that can be used to establish a longer-term assessment of change in extent, providing a baseline that is much less impacted by development. It is possible to convert these images (e.g., Figure 10) to a digital format so that they can be used for a direct comparison with more recent EO images. An alternative (or addition) to the use of aerial photographs, is the use of topographical maps. These maps were developed using laborious ground- and aerial-based techniques before the availability of satellite images became practical. These maps can be used to provide a baseline at dates prior to the availability of EO data. Google Earth images are also a valuable source that includes historical imagery.

TABLE 7. AGENCIES AND SATELLITES TO DETERMINE THE EXTENT OF WATER-RELATED ECOSYSTEMS.

SATELLITE SENSORS PRODUCING IMAGES OF WATER-RELATED ECOSYSTEMS	SOURCE
ALOS PALSAR, ALOS-2 PALSAR-2, AVHRR, Envisat, ERS-2/SAR, Ikonos, IRS, JERS-1 SAR, Landsat, MODIS, QuickBird, Radarsat Sentinel (several), Spot, WorldView	▪ http://reverb.echo.nasa.gov/reverb (NASA) ▪ https://lpdaac.usgs.gov/data_access/data_pool (NASA) ▪ http://www.satimagingcorp.com/gallery/more-imagery/spot-5/ (SPOT) ▪ http://en.alos-pasco.com/ (ALOS PALSAR) ▪ https://sentinel.esa.int/ *(Sentinel)* ▪ http://scihub.Copernicus.eu/dhus/#/home (ESA Copernicus) ▪ http://glcf.umd.edu/data/quickbird/ (QuickBird) ▪ https://worldview.earthdata.nasa.gov/ (WorldView) ▪ http://glcf.umd.edu/data/ikonos/description.shtml (ikonos) ▪ https://www.asf.alaska.edu/sar-data/jers-1/ (JERS-1 SAR)

TABLE 8. SUMMARY OF REMOTE SENSORS APPLICABLE TO MONITORING OF WATER-RELATED ECOSYSTEM EXTENT.

SENSOR/SATELLITE	AGENCY	RESOLUTION (M)	REVISIT TIME (DAYS)	AVAILABILITY	START YEAR	STATUS
ALOS PALSAR	JAXA	7-44	46	Commercial	2006	Inactive
ALOS-2 PALSAR-2	JAXA	3 – 10	14	Free and commercial	2014	Active
ASTER	ASTER	30	sporadic	Free		Active
AVHRR	NOAA	1000	1	Commercial	1998	Active
Envisat	ESA	30	3	Commercial	2002	Inactive
ERS-2/SAR	ESA	26	35	Commercial	1995	Active
Ikonos	Space imaging	0.82 - 3.2	3	Commercial	1999	Active
IRS	IRSO	5 – 70	5	Commercial	1988	Inactive
JERS-1 SAR	JAXA	18	44	Commercial	1992	Inactive
Landsat	NASA	30	16	Free	1972	Active
LANDSAT 8	NASA	30	16	Free	2013	Active
MODIS	NASA	1000	2	Free	1999	Active
QuickBird	DigitalGlobe	2.5	3	Commercial	2001	Active
Radarsat	Canada	10 - 100	6	Commercial	1995	Active
Sentinel	ESA	10 - 60	6	Free	2014	Active
Spot	ESA	2.5 - 10	5	Commercial	1986	Active
WorldView	DigitalGlobe	0.5	1	Commercial	2007	Active

3.7.8. Ground-based observation as a source of data collection

It is noted above that remote sensing methods generally require some level of ground-based verification. How much ground-based or in situ survey is necessary for verification of EO data? This depends on the required confidence in the output; the more verification that is done, the greater the confidence in (and accuracy of) the final product. However, it is useful to establish an optimum verification level that could be used generally at the national level.

Besides the verification of the extent of water-related ecosystems (e.g., the perimeter of wetlands), ground-based surveys of spatial extent are used where local ecosystems are suited to direct survey, e.g., for the extent of priority Ramsar registered wetlands. An advantage of this approach is that the characteristics and health of the ecosystem can be assessed and mapped at the same time (e.g., the distribution of different vegetation types) which helps in understanding the changing dynamics of the ecosystem.

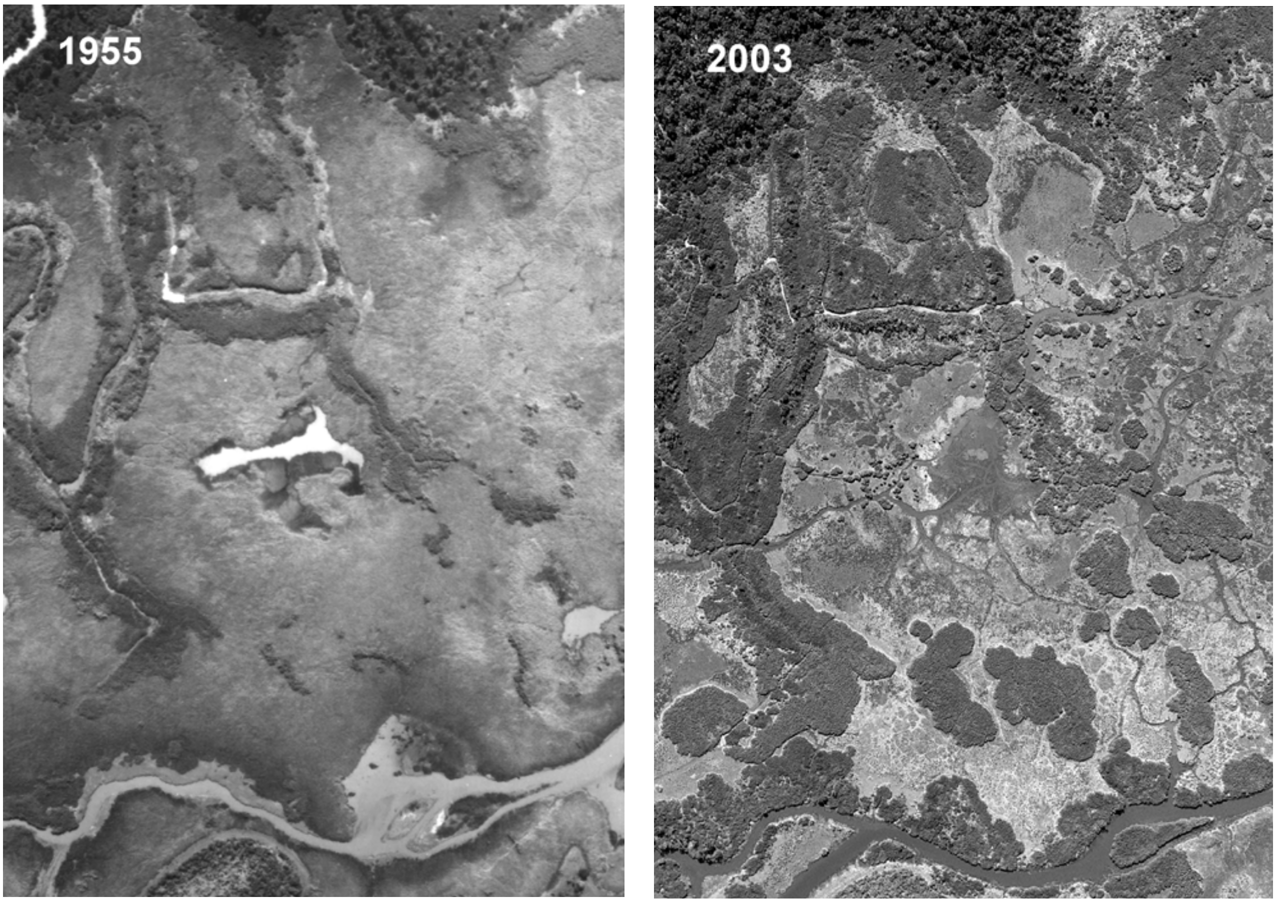
Ground-based verification (or ground-truthing), based on the nomenclature that has been used for the mapping, will need to be done initially with some rigor, to ensure that the results of the analysis of the EO data have the required confidence. It is recommended that consideration at the national level be given to the percentage of water-related

TABLE 9. EARTH OBSERVATION OPTIONS FOR THE DIFFERENT SUB-INDICATORS AND ECOSYSTEM COMPONENTS.

ECOSYSTEM TYPE	COMMENT	RESOLUTION	POSSIBLE SATELLITES AND SOURCES OF DATA
Vegetated wetlands / swamps / marshes (including swamps forests)	▪ Not possible at the global level without verification. ▪ Possible to do at the national level (needs local classification). ▪ Seasonality of many wetland types (such as floodplains, artificial wetlands, rice paddies, seasonal marshes) are important but should not detract from the overall change in extent.	10-30m	▪ Sentinel 1 and 2, LandSat (all), ALOS PALSAR 1 and 2 ▪ ESA Sentinel-2A provides 10-day repeat coverage of Earth's land areas, which in combination with the 8-day coverage from Landsat 8 and NASA Land Use/Land Cover Change will give better-than-weekly coverage at moderate resolution.
Peat	▪ Optical data (Sentinel 2 data) for extent + Radar data for changes. ▪ Ground-based verification is necessary. ▪ Classification: Temperate, boreal separate from tropical. ▪ Peatlands can be distinguished by the tree species, tree structures, soil type and topography (raised bogs). ▪ It is not feasible to do an accurate inventory on a global level for all temperate/boreal and tropical peatlands. Dense canopy and drained peatlands are especially problematic. On a national level, it is feasible to monitor known peatland areas using the sensors mentioned when a good national/regional inventory exists.	10-30m	▪ ALOS-2 PALSAR-2 + Sentinel -1, LandSat 8, PALSAR2, MODIS. /2 (changes) ▪ ICESat/GLAS (LIDAR) ▪ Optical data ESA Sentinel 2 data for extent; Radar data for changes with ground-based verification; RAMSAR has national maps for arctic peats.
Estuaries tidal flats	▪ There are many available maps of tidal flats. ▪ Not possible at the global level without verification. ▪ Possible to do it at the national level (needs local classification).	10 – 30 m resolution	▪ Sentinel 2, Landsat 8
Cultivated wetlands (paddy rice, flood recession farming)	▪ Classification approaches such as those used in the IWMI irrigated area mapping initiative can be used to determine certain irrigated wetlands. Known seasonal dynamics are used to separate data from natural wetlands.	30-250 m	▪ Landsat 8, MODIS, Sentinel, PALSAR (requires a good time series capture seasonality)
Mangroves	▪ Possible at the global level. ▪ Ground-based information necessary for verification. ▪ Ongoing initiative (Global Mangrove Watch).	25 m resolution	▪ PALSAR2, Historical baseline: JERS-1 SAR + ALOS PALSAR + Landsat ▪ Future: ALOS-2 PALSAR-2 + Sentinel 1, LandSat 8 ▪ World Mangrove Atlas (UNEP-WCMC); JAXA Global Mangrove Watch
Ponds/ lakes/ open water bodies	▪ Distinction between natural and artificial open water requires intervention (e.g., a map of reservoirs can be separated from all open water using GIS).	10-30m	▪ Sentinel 2 – 10 m Sentinel 1 (VH or HV-pol) - 30 m ▪ PALSAR global mosaic – 25 m ▪ Landsat 8 – 30 m ▪ Global Land Surface Water Dataset in 30 m ▪ Global Surface Water Project based on Landsat imagery. https://global-surface-water.appspot.com/ ▪ Global System Water Project GRaND and with socioeconomic data Ciesin GRaND ▪ http://land.copernicus.eu/global/products/wb http://www.esa-landcover-cci.org/?q=node/162 http://glcf.umd.edu/data/watercover/
Rivers/ floodplains	▪ Constrained rivers are not suitable for EO as they do not alter substantially with changing flow. ▪ Floodplains and wide meandering rivers are possible; however, in many cases discharge may be a more appropriate measure of change.	10 - 30m	▪ Sentinel 2 ▪ River Global Land Surface Water Dataset in 30m; River HydroSHED[3] and HydroBASINS (USGS, WWF); Flood plains PREVIEW Global Flood Model (UNEP, UNISDR)

[3] Hydrological data and maps based on Shuttle Elevation Derivatives at multiple scales. HydroSHEDS is a mapping product that provides hydrographic information for regional and global-scale applications in a consistent format. It offers a suite of geo-referenced data sets (vector and raster) at various scales, including river networks, watershed boundaries, drainage directions, and flow accumulations. HydroSHEDS is based on high-resolution elevation data obtained during a Space Shuttle flight for NASA's Shuttle Radar Topography Mission (SRTM).

FIGURE 10. EXAMPLE OF AERIAL PHOTOGRAPHS ILLUSTRATING A CHANGE IN THE EXTENT OF WETLANDS OVER TIME, IN THIS CASE THE PONGOLA FLOODPLAIN IN SOUTH AFRICA.



The 1955 picture shows a healthy coverage of wetland vegetation, while in 2003 there is encroachment of terrestrial vegetation as the land dries out. Flooding had been reduced by an upstream dam. *Source:* Lankford et al. 2010.

ecosystems that need to be verified on the ground, and a national standard be established. Verification of remotely sensed data can also be done using Google Earth images, but again this should be accompanied by field surveys. The degree of verification will be related to acceptable error levels and the purpose to which the results will be put. Ultimately, this will be a process whereby the amount of effort put into ground-based verification will be adjusted depending on the type and resolution of the EO data, and the level of detail required in the final mapping product.

Ground-based verification purely for the purpose of determining the extent of wetlands essentially consists of comparison of the perimeter of the wetland derived using survey methods (see the section below), with the perimeter derived from EO. Where differences are consistent, the EO-based assessments will need to be adjusted accordingly. The final approach used may then be extended to other similar ecosystems that have not been verified; national "priority" ecosystems should, however, always be verified on the ground.

Prior to the availability of EO technologies, ground-based delineation of the extent of wetlands (in particular palustrine or vegetation dominated) was common practice. While these methods are appropriate for SDG indicator monitoring, their limitation is a practical one, as it is not always feasible for all the wetlands in a basin or country to be mapped using these techniques. Methods that may be used include monitoring the extent of soils reflecting saturation with water (such as USDA 2010) and vegetation patterns reflecting the boundaries of the wetland (Environmental Laboratory 1987).

Ground-based verification is also essential in the situation where the assessment of the EO data has identified a substantial change in the extent of a wetland over time. The ground-based survey is needed in this situation to not only verify the result, but also to assess the nature, and in some cases the cause of the change. Other types of water-related ecosystems (floodplains, lakes, mangroves, etc.) require a similar process to determine the perimeter of the particular ecosystem.

3.7.9. Spatial scale and frequency of observation

Earth Observation (EO) images are collected by the space agencies at regular (sub-monthly) frequency; thus assessments can be made as frequently as is appropriate for the ecosystem and country situation. Because of the natural seasonal wet-dry cycles that occur in many places, sufficient data need to be gathered to cover at least the extremes of the wet and dry periods. However, cloud cover may obscure the land and obstruct the collection of data from optical sensors (SAR data can still be used), so care needs to be taken in generating seasonal estimates of extent from these data.

The objectives of SDG monitoring are to detect long-term changes in the sustainability of the ecosystems, and thus short-term and transient changes in extent are not the main issue. SDG monitoring is not intended to capture changes in extent that may be the result of climate variability (e.g., between wet and dry seasons, and even between wet and dry years). This type of changed extent will need to be understood to be able to compare the change in extent over time, e.g., the long-term change could be measured by recording extent only at the peak of the wet season, or the dry season, or at a percentile in between. The seasonal fluctuations do provide useful indications of seasonal impacts by society, e.g., maximum abstractions of water for irrigation usually occur during the dry season.

It has been proposed that SDG reporting should take place once in four years. This time frame is short for documentation of a meaningful change in extent of most ecosystems; however, as this develops into a longer time-series this will become increasingly useful. Identifying change soon after it occurs is advantageous in that interventions can be taken to prevent further degradation.

One of the strengths of EO data is that it is typically collected globally and at regular time intervals, so that complete sets of data are available for most countries covering various seasons. For example, ESA Sentinel-2A provides 10-day repeat coverage of Earth's land areas, which in combination with the 16-day coverage from NASA's Landsat mission will give better-than-weekly coverage at 30 m or higher spatial resolution. The rapid and comprehensive coverage of EO data is a major utility in monitoring the different types of water-related ecosystems.

The minimum frequency for measurement of the extent of water-related ecosystems recommended is that a detailed collection and interpretation of both EO and ground-based data should be made once every four years (as required for SDG reporting). Where historical data are available, a long-term trend should be determined.

Earth Observation (EO) provides an ideal approach for monitoring as it includes global coverage of the extent of water-related ecosystems. It is recommended that EO data be used where possible for country reporting, to obtain an overall assessment of the spatial extent of water-related ecosystems for an entire country. Countries may then choose to assess the situation at a finer spatial scale (e.g., for specific sites) which may provide information of greater value for country-based management. For example, monitoring individual priority wetlands within a country (such as Ramsar sites) over time should be an objective and may form a part of the SDG monitoring.

3.8. Representation of data and results

Earth Observation data are spatially continuous, with data represented in grid format where each grid cell represents a single value. For example, Landsat images have a resolution of 30 m meaning that all features less than 30 m are mapped as one single feature within that 30-m grid cell. The data on spatial extent of water-related ecosystems can be aggregated into political or hydrological units where, for example, a country may be illustrated by a single color on a map. This type of representation may be more useful when global or regional assessments of the "average" situation are being carried out or regional patterns are being assessed. However, this may not be the most useful for management purposes where local ecosystem-level monitoring needs to be done and where detailed maps of each ecosystem type are produced, in this case by using GIS. Thus, the change in extent of water-related ecosystems could be presented as a percentage change per ecosystem, per region or at the national level.

A more rigorous and statistical approach can be adopted where data are assessed for regions as well as for ecosystem types. These data can be summarized statistically in tables or in graphs. In the Text Box below is a summary of the Wetland Extent Trend Index (Dixon et al. 2015) which has been produced to deal with heterogeneous data on the extent of wetlands and can be used to produce regional and wetland type reports. It must be noted however, that the approach for country reporting is likely to be more direct and based on the collection of EO data and ground-truthing, with interpretation of data done in GIS.

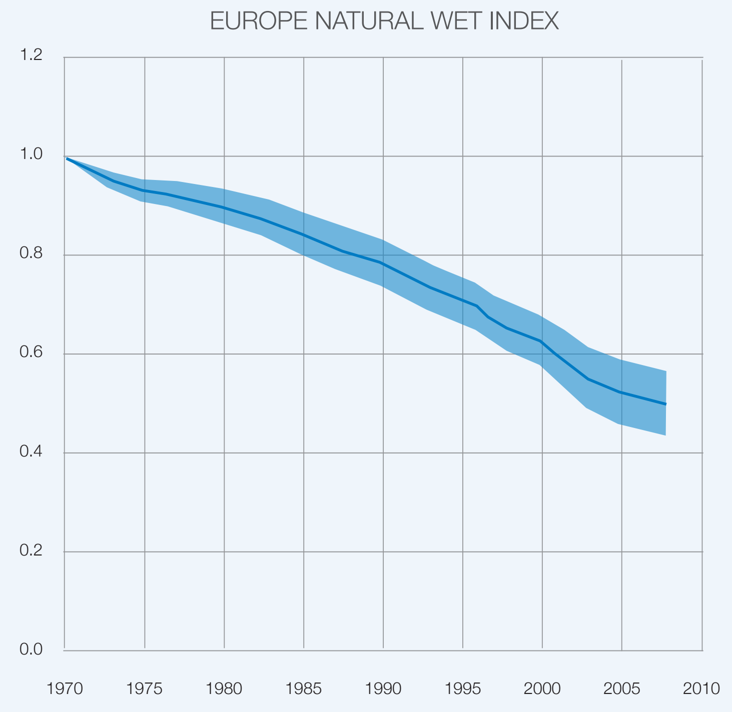
One of the challenges associated with the measurement of spatial extent, is that the extent of many water-related ecosystems change naturally on an annual basis, as they flood and dry out in response to natural wet and dry seasons. This poses a challenge in that the results could be spurious, if not measured at corresponding stages of the seasonal change. It is thus advisable to standardize the seasonal stage used for monitoring of this indicator, or to adopt an approach that is insensitive to seasonal fluctuations. For example, the maximum water level is unlikely to be a useful measurement as very transient flood waters may be measured which have no real relation to the extent of the water-related ecosystem. Thus, for example, a wetland may flood into a terrestrial ecosystem which has none of the characteristics of a wetland, i.e., hydromorphic vegetation, etc. An approach to be sure that the true extent of vegetated wetlands is being measured,

THE TREND INDEX OF THE EXTENT OF WETLANDS

Over the past years, UNEP-WCMC and others have been involved in drafting a method for collation and interpretation of data on the extent of wetlands. This method is a possible approach to collation of the SDG data, and also serves the Ramsar Convention and CBD under Aichi Target 5 (reduction in the rate of loss of habitats). The method is the Trend Index of the Extent of Wetlands (Dixon et al. 2015). This method can estimate broad trends in extent for habitats with incomplete and heterogeneous data. While the method was designed to assess extent based on the data on irregular and uneven coverage of the extent of wetlands as published in the literature, the approach is also suitable for dealing with the range of heterogeneous data from different sources that will be collated at both country and global levels. These data are likely to be heterogeneous both geographically and thematically, i.e., there are more studies on wetlands in North America than in the Neo-tropics and more extensive datasets for mangroves than for lagoons. The Index estimates the average rate of change in the extent of wetlands using a variation of the Living Planet Index methodology (Loh et al. 2005; Collen et al. 2009) to combine extent trend data. Practically, what this may mean for the Target 6.6 Indicator reporting is that some countries, for some ecosystem types, will have greater amounts of data, especially in situ data, than other countries. While the EO data will be collected evenly for the entire globe, not all countries will have the same resources to access and interpret that EO data and. in particular, to carry out ground-verification. This will lead to an uneven distribution of data.

In the proof of concept study carried out by UNEP-WCMC (Dixon et al. 2015), they used time series from 170 source references which were entered into a database. Each record was tagged with its Ramsar Region (Africa, Asia, Europe, North America, Neo-tropics and Oceania), sub-region, wetland characteristic data (e.g., wetland type: marine/coastal, inland or human-made) and source reference. To account for geographical unevenness, the data were then further subdivided into 126 sub-regions and 20 wetland classes (i.e., subtypes), making a matrix of 2,520 possible combinations. The average trend in the extent of wetlands was then calculated for all wetlands in each cell of the matrix for which one or more time series were available, making 1,100 average trends in total (1,420 cells had no data).

To generate the indices, the average trends for individual sub-region-wetland class combinations (matrix cells) were then aggregated, giving each cell equal weight, and analyzed using the Living Planet Index methodology. The index does not show the change in the extent of wetlands that happened before 1970, which was extensive in some regions such as Europe where there is a long history of wetland drainage. The index uses the methodology developed for the Living Planet Index to calculate an average change in the extent of wetlands over time (from a baseline of 1970 = 1), drawing on data from any available published source. The index can be disaggregated geographically and by wetland type given sufficient data. It can also be continually enhanced and updated as new data on wetland change becomes available and is added to the database. NOTE: This approach is not being recommended for detailed country-level reporting (a bit surprising since this, at least, provides a consistent methodology that would enable inter-comparison! It could be a starting point from which to build?), where a more direct GIS approach is possible.



Example of the WET Index output showing a decline since the baseline in 1970. Trend line with 95% confidence limits, extracted from Dixon et al., 2015.

is to include measurements of the ecosystem that are less influenced by transient changes in water level, such as vegetation type and soil morphology or chemistry.

A further challenge in using EO is that clouded images or images from mountainous areas are not as easy to interpret as are images of flat areas, since water bodies can be confused easily with mountain shadows (in particular in radar satellite data) or cloud shadows (in optical satellite data).

A description of the Globwetland project, presented below gives a summary of a direct approach to the determination of extent of wetlands that is possible using EO.

3.9. Setting targets

That the setting of targets or objectives for the extent of wetlands has become a global priority, is documented by Davidson (2014) who noted that globally estimated wetland conversion and loss in the long term is in excess of 50% and as much as 87% since the beginning of the eighteenth century; wetland loss was almost four times faster in the twentieth century than earlier, with losses of up to 70% of wetlands existing in 1900 AD. Conversion of coastal natural wetlands accelerated more than that of inland natural wetlands in the twentieth century; and conversion and loss are continuing in all parts of the world, and particularly rapidly in Asia. The fate of the world's remaining wetlands is, thus, very uncertain, and would be supported by society making clear decisions on how much loss is acceptable.

While the SDG process sets out to monitor the percentage change in the extent of water-related ecosystems over time, it will be incumbent on countries to actually set Targets for this change, to determine what is an acceptable change and when and how management interventions should be introduced. Countries such as the USA, Canada, and South

THE GLOBWETLAND II PROJECT EXAMPLE

It is important to appreciate the high dynamics of wetlands since surface water and soil wetness can change rapidly depending on the seasonality of rainfall. For this reason a long time series of satellite observations is necessary in order to undertake a precise mapping of the extent of wetlands, which can be linked to other data sources. This is explained for GlobWetlands II below (Marc Paganini European Space Agency – pers. com.).

In the GlobWetland II project there was existing knowledge about the location of wetlands (in the form of a coarse delineation) to which was added a time series (to capture the inter-annual variations) of Landsat images to classify the vegetation and the changes in surface water. This information was then used to delineate more precisely the extent of wetlands. In this case, the soil moisture (soil wetness) was not analyzed, and the extent of wetlands was based on the type of vegetation (discriminating wet meadows, marshes, agricultural fields, aquaculture, built-up areas, etc.) and the presence of surface water (permanent and seasonal).

This procedure is well established now, but requires a priori information on wetland location and uses a supervised classification approach with the classifier trained in using ground data detailing the location and type of vegetation. This makes the process quite intensive in terms of expert involvement but gives a precise delineation. It is difficult to apply globally due to the a priori knowledge needed and the level of user involvement.

The mapping of the extent of wetlands is very different if you have no a priori indication of where the wetlands areas are. This is the common situation, and necessitates inventories over a large geographical area. This procedure is less mature but is likely to be more appropriate for global mapping of the extent of wetlands, and requires a more automated approach (which can include regional or thematic customization) which differs from that described above. In this case, topographic information together with information on soil wetness (using surface soil moisture information) and from the surface waters (including inundated vegetation) needs to be incorporated. The challenge here is to have precise information on the soil wetness (In GlobWetland Africa an index called Soil Moisture Index is used) in order to delineate wetlands. It is thus based on a combination of information on the topography, the water content of the soil, the presence of surface water, with perhaps no discrimination of the type of vegetation. This product requires an approach based on both radar and optical observations since information on soil moisture can only be retrieved from radar measurements. The process requires less expert involvement and will produce a less precise delineation of the extent of wetlands. It is, however, more appropriate for estimation of the extent of global and regional wetlands.

The H2020 project SWOS developed a standard to delimitate the mapping area. The SWOS approach for the delineation of wetlands is based on a delineation of potential wetland areas using the topographic wetness index and an object based classification of wetland land cover types.

Photo: Chris Dickens/IWMI

Africa have set a "no net loss" policy following the guidance and recommendation of the Ramsar Convention (Ramsar COP11 2012), which suggests that any loss of wetland resources needs to be compensated by rehabilitation of a greater number of resources. Countries may set an alternative target but this must be justified, and as described by Aichi Biodiversity Target 5, the rate of loss should at least be halved but ideally approach zero. Aichi Biodiversity Target 15 aims to restore 15% of degraded ecosystems that store carbon (wetlands, peat).

4. SUB-INDICATOR 6.6.1.B: PERCENT CHANGE IN QUANTITY OF WATER OVER TIME

4.1. Scope

This sub-indicator measures the quantity of water stored within water-related ecosystems. Such a measurement provides key information on both the amounts of water present in the ecosystem and maintaining ecosystem processes; it also provides a source of water for society. Without the requisite quantities of water stored in the ecosystem, most of these ecosystems would vanish. However, the indicator is limited in that it only captures the quantity of water stored in flowing rivers, open water bodies such as lakes, and also in major underground aquifers. It does not capture the large amounts of water stored and used in the ecosystem, as soil moisture, as water in shallow vegetated wetlands or marshes, or in the snow, glaciers or ice caps! It also does not deal with the critical aspects of interaction between groundwater and surface water, or how variation in stored water causes changes in the surface ecosystem. Many of these aspects can be further investigated by making use of some of these data produced by the 6.6.1 indicator method.

The quantity of water in ecosystems is dominated in most countries by the amount of water contained in rivers, measured as streamflow, together with the water stored in lakes and reservoirs, and also beneath the ground. Over time, the consumption and redistribution of water from these different water "reserves" may lead to a depletion of the quantity with direct consequences for aquatic ecosystems. In severe cases, water resources have been completely "dried up", which may result in a complete loss of water-related ecosystem services not only in the location of the ecosystem but also downstream. Thus, this sub-indicator of Target 6.6.1 measures the quantity of water contained in various water-related ecosystems including rivers, lakes and reservoirs, and groundwater.

A key aspect of this sub-indicator that is not directly measured but is inferred, is that the quantity of water in ecosystems is not only of value to society, but needs to be managed to protect the ecosystem itself. The quantity of water required to maintain ecosystems is often referred to as "environmental flows" or "environmental water requirements". The Brisbane Declaration (2007) defined these as *"the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems".* Understanding of these flows is an important part of ensuring that water-related ecosystems are protected and continue to provide services. Environmental flows form a part of indicator 6.4.2, which however contribute to indicator 6.6.1 by providing a target that can be used to assist with management of the resource.

4.2. Source and collection of data

4.2.1. Flow or discharge in rivers

Streamflow can be modeled based on rainfall and the prevailing land use, or it can be directly measured in the river. Monitoring of the streamflow or discharge of rivers has been in place for decades in most countries and has generally involved the location and monitoring of streamflow stations at strategic points within a basin. These may be constructed gauging stations (weirs) or alternately the natural channel is "rated" so that a simple measure of depth can be used to calculate the flow.

Collection of streamflow data generates statistics that describe the volume of water flowing past a point in a river over time. This includes the total volume per year, the extremes of high and low flow, the mean and median flows, and the distribution of flow over the course of the year. All these statistics are necessary to understand streamflow and its relationship to an ecosystem. Which statistic is used to represent the annual flow is a matter of opinion; however, the mean flow is the most commonly used. However, when the mean and median flows of a river are substantially different (e.g., when a river is highly variable with large floods) then the median flow may be the most robust. Note that the 6.6.1 data reporting form recommends the use of the mean.

The approach to monitoring streamflow may thus be either one of the methods below, or a combination of both. Note that SDG indicator 6.4.2 (Water Stress) also includes a value for the Mean Annual Runoff (MAR), which data may also be used here.

1. Direct monitoring of the flow in rivers and statistical interpretation of the change in mean annual flow from the "natural" reference condition. The mean statistic is recommended to be used for these estimates although local circumstances may demand that an alternative statistic be used; but this should be consistently used in that situation. In this approach, it may be necessary to model the "natural" reference flow if suitable historical flow data are not available. Ideally, a data record of >50 years should be available to ensure that short-term changes are not impacting on the conclusions. When making a comparison of the present observed mean annual flow and the natural flow, a 5-year moving average is recommended to be used to represent the present flow, which will remove some of the short-term variability.

2. Modeling the change in flow using a tool that makes use of rainfall and land cover amongst other data to determine both the natural flow and the present flow. There are global models set up for this, and in some countries, these or similar models are developed for the local situation. These models should be calibrated using real measured data to ensure that the modeled data approximate the real situation.

3. A third possibility is that measurement of flows from satellites will be available in the near future, starting first with large rivers and then extending to smaller rivers. Countries will need to keep abreast of these developments.

4.2.2. Quantity of water in open bodies of water such as lakes and reservoirs

Besides rivers, stationary water (lentic or lacustrine ecosystems) as found in lakes and ponds are an important element of storage in many basins. This also includes man-made reservoirs. The volume of water in lakes and man-made reservoirs is monitored using either EO to measure open water surface area and also height of water surface (above sea level), or ground-based surveys to measure area and bathymetric depth. The indicator is calculated using a combination of surface area and maximum depth or, for improved results, the contours of the lake bottom. Once the relationship between height of surface water and volume is established, then measurement becomes a simple affair of reading the height of water from a gauge plate. Normally, the measurement of the bottom of the water body need only take place infrequently (decadal) unless there are major inputs of sediment resulting in a rising substrate. Earth Observation can be considered as a tool to measure not only the height of water surface, which it can do to within an accuracy of 10 cm but also the area of surface water.

Interpretation of the results collected from the monitoring of man-made reservoirs is often confounded by the rapid changes induced by management practices, which may have no connection to long-term environmental change. Interpretation may, thus, be difficult in determining the long-term trends divorced from rapid operational changes. However, the volumes of water stored in reservoirs may be substantial and these quantities need to be included in estimations of overall catchment storage and the changes over time. Thus, in the same way as for river flow, a 5-year moving average of water volume is recommended to be used to calculate the mean storage of a reservoir.

The data are used to determine the change in the quantity of water in open water bodies over time, making use of a reference which is ideally as close to "natural" as possible. Note however, that for the 2017 reporting period, only the 2017 baseline will be reported (the 5-year mean), and not the change over time.

4.2.3. Groundwater volume/depth

Storage of groundwater is difficult to measure as in large parts of the world the aquifers containing groundwater have not been adequately mapped and/or characterized. However, in many parts of the world groundwater is the most important water resource and it is therefore crucial that it is included in this indicator. Groundwater volumes change as a result of changes in groundwater recharge (affected by climate conditions and land use) and by anthropogenic removals from the system (groundwater abstraction). The volume of water stored in aquifers has to be estimated from the areal extent of aquifers, their saturated thickness and Storativity also known as Storage Coefficient.

Changes in volume of groundwater can be inferred from changes in groundwater levels. Collection of the groundwater table depth is a simple measurement of the depth to the groundwater within a borehole. However, the challenge is in the location of the boreholes (expensive to construct) and whether these adequately represent the total groundwater situation for an area. Point measurements of changes in the depth of groundwater levels need to be integrated over the whole surface area of an aquifer (or if individual aquifers are unknown: over the surface area of a region/country). This can be done by means of interpolation (various interpolation techniques are available and the suitable technique depends on the amount and type of available data). Groundwater models can also be used to 'interpolate' point measurements and models have the advantage that they will calculate gradients based on aquifer characteristics, rather than on statistical methods only. This will need to be done at the national and local levels and should be designed to ensure that the data produced are of value to national and local water management.

An important consideration for estimating the depth to groundwater or depth to 'water-strike' is whether the aquifer is confined or unconfined:

For a phreatic or unconfined aquifer (i.e., under atmospheric pressure) this is simple and is equal to the depth of the water table. However, for a confined aquifer the water level (the potentiometric level/pressure head) would give an overestimation as the water is forced higher than the water confined within the rock structure. Here it is necessary to know the top of the aquifer (=bottom of confining layer) which is normally known from original borehole records, or general hydrogeological knowledge. This is based on the description of geology or on borehole records, in particular the 'depth to water strike' which is a good indicator normally recorded on the borehole log during drilling (Geert-Jan Nijsten, pers. com.).

IGRAC (UNESCO centre on groundwater) maintains a database on groundwater levels worldwide (Global Groundwater Monitoring Network) and also data on aquifers, which are all available through the Global Groundwater Information System (GGIS).[4]

Remote sensing also provides tools for indirect monitoring of groundwater from space. Changes to groundwater table can be calculated using data from the GRACE[5] mission (NASA), which notes that "by observing changes in the Earth's gravity field, scientists can estimate changes in the amount of water stored in a region, which cause changes in gravity. GRACE provides a more than 10-year long data record for scientific analysis. Using estimates of changes in snow and surface soil moisture, scientists can calculate change in groundwater in volume over a given time period." Limitations of GRACE are the low spatial resolution and the need for additional ground data or models to separate groundwater storage fluctuations from other water storage fluctuations (soil moisture and surface water), but the technique is promising for large regions with no/little direct data on groundwater levels.

4.3. Scale and frequency of monitoring

This section considers the frequency of monitoring, i.e., how often surveys should be carried out. The scale refers to the geographical extent of that monitoring and the number of survey points that would be necessary to represent an area, or a river of a particular length.

4.3.1. Flow in rivers and estuaries

The volume or quantity of water in a river and also the extent of change from the natural situation, can, and do, change as the river flows downhill through its catchment or basin. The minimum monitoring effort would be to locate a flow measuring site at the exit from all significant basins or to model the flow in entire basins. In addition, monitoring at the exit from all major tributaries adds a substantial level of information. Where there is an uneven impact on streamflow due to human influence, then it is recommended to monitor flow upstream and downstream of these areas so that the overall situation can be managed.

Note that where a river is transboundary, the total discharge in the river remains relevant for this indicator as it is a measure of total water availability that is required, not a measure of production of water. Thus a downstream country will report total river flows, not just the incremental additions to flow that have taken place within that country (NOTE that this has important implications for interpretation of the data as it will not be correct to add the total water volume per country to arrive at a global total). To illustrate that this is a necessary perspective, take for example a large river entering a desert country where there is no additional rainfall or water addition. It must be reported that this country indeed has a volume of water as part of its resource, even if this volume all originated outside the country. This aligns with SDG Indicator 6.4.2 which makes use of Total Renewable Water Resource in a country (in km^3/annum) comprising Internal (generated within the country) and External (generated outside the country) water resources.

The quantity of water in a river changes rapidly in response to rainfall; thus, monitoring needs to be carried out at an appropriate frequency. Data on river flow should be preferably collected daily but can be aggregated to monthly flow to enable analysis of the larger trends in flow. Daily flows are, however, significantly more informative for evaluating the interaction of streamflow with the ecosystem. Most countries will already have a database of river flow at the national level and there are global databases[6]

[4] https://www.un-igrac.org/global-groundwater-information-system-ggis
[5] http://grace.jpl.nasa.gov/applications/groundwater/
[6] Global Runoff Data Centre http://www.bafg.de/GRDC/EN/Home/homepage_node.html; Aquastat http://www.fao.org/nr/water/aquastat/water_res/index.stm

of flow albeit with greater uncertainty. Where historical data are available, then a long-term trend should be assessed and the "natural" reference determined either using flow records or by modeling.

The quantity of water in estuaries may be significantly influenced by tidal inflows. This indicator is limited to the freshwater inflows to the estuary from the upstream river.

Streamflow data from models, especially global models, require that a great deal of data are incorporated into the models in order to update them. Accordingly, these data may be more than a year old before the model can be used to produce information for reporting. This poses a challenge for SDG reporting which will be done at four-yearly intervals, in which case the results produced will have to be clearly date-stamped.

4.3.2. Quantity of water in open water bodies such as lakes and reservoirs

It is not possible to monitor the quantity or volume of water in all water bodies, large and small, as there are simply too many of them. This effort should be reserved for significant water bodies (countries will need to determine which are significant). Data from natural water bodies which are not subject to rapid withdrawals should be collected at least at the extremes of the dry and wet seasons, but ideally monthly. Volumes of significant artificial reservoirs subject to intensive management, should be monitored at least monthly.

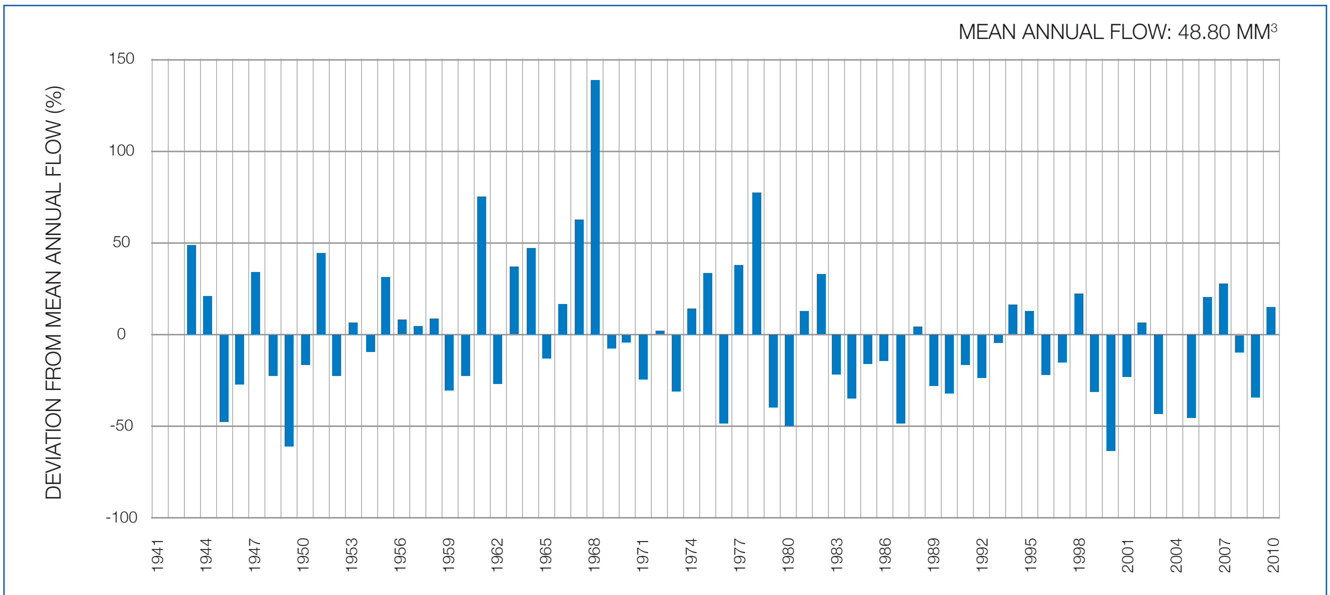
Water quantities can vary over time due to seasonal and wet/dry cycles, which should not be allowed to obscure the long-term changes. Seasonal changes can however be used to understand the use of water from surface water especially where this is done differently in the dry versus the wet season. Where historical data are available, then a long-term trend may be assessed. At a minimum, a baseline of 2016/17 should be set as a reference.

4.3.3. Groundwater depth/volume

Monitoring of groundwater (depth to the water table for unconfined aquifers, i.e., those where the water is at atmospheric pressure/depth of groundwater pressure levels for confined aquifers, i.e., those aquifers under pressure from the weight of rock above) needs to be based on the location of important groundwater aquifers. The number of boreholes that need to be monitored cannot be prescribed because the distribution of groundwater can be variable depending on the location and characteristics of aquifers. Sufficient boreholes to characterize the area are recommended to be monitored, with the capacity of the country being a factor in deciding how many would best represent the area. It is highly recommended that data should be taken from observation boreholes/monitoring boreholes (these are boreholes which are not equipped with pumps). Data from used (pumped) boreholes should be avoided. In case a pumped borehole needs to be used for measurements then it is crucial to allow for a sufficiently long recovery period in which the borehole is not used so that the groundwater level in the borehole can stabilize prior to the measurement.

There is one challenge with the reporting on groundwater for indicator 6.6.1.b and that is how to report this in a way that is meaningful as part of global SDG reporting, and also useful for country-level management. While expert opinion on groundwater would generally support the perspective that the groundwater data should be reported per aquifer irrespective of surface water distribution, the SDG implementation process has seen the need to rather align the groundwater report with the surface water, purely to streamline reporting which is done on a basin scale (for water resources). This means that to estimate the volume of groundwater available at the basin scale, a simple division of the aquifer based on its spatial distribution should be made using GIS, using basin and political boundaries as appropriate. Where a country has sufficient information, then it would be possible to determine the actual aquifer contribution to the extent of water resources of a surface-water basin.

FIGURE 11. ILLUSTRATION OF THE CHANGE IN RIVER FLOW OVER TIME (FIGURE MATTHEW MCCARTNEY).



Seasonal and wet/dry cycle influences need to be filtered out for long-term SDG monitoring and hence monthly monitoring is optimal, but at least twice per year is necessary to capture both the high groundwater levels (usually during or soon after the wet season) and the low groundwater levels (usually at the end of the dry season or soon after). Information on seasonal change is also important in understanding the pressures on groundwater, e.g., which seasons are those where there is most abstraction from the groundwater. Where historical data are available, then a long-term trend may be assessed. At a minimum, a baseline of 2016/17 should be set as a reference.

4.4. Representation of Target 6.6.1.b data and results

Because water quantities generally change with some rapidity, it is appropriate to reduce these data to representative statistics, such as mean or median flow, or some suitable percentile with 95 percentile being commonly used. Maximum flows or volumes are less useful and do not represent the general situation as they may be dominated by single flood events. More useful alternatives are the median annual flow, or the total volume per annum, both of which can be used to determine the change from Natural Reference to the present. It is also possible to make use of an estimation of trend, but this would need to be converted to percentage change over time.

4.4.1. Streamflow

Streamflow represents one of the key sub-indicators of the Target 6.6.1 indicator, because the quantity of water in any water-related ecosystem is key to sustainability of that ecosystem. The deviation of mean (or median) annual flow from a natural or reference flow, expressed as a percent, is the basis of this indicator. Using the mean (or median) of a 5-year moving average is recommended, which will serve to smooth any short-term variation, especially the influence of large floods.

Medium-term rainfall variability will cause a natural variation in the total flow of a river from year to year; thus it is only over several decades that the flow statistics become reliable and it is possible to determine the trends in change over time. It must be cautioned that short-term hydrological data can give very spurious result!

For example, the graph presented in Figure 11 shows a typical situation where there is high annual variability in flow, but there is a possible change in river flow in the late 1970s with below "average" values from this point onwards. This could be attributed to anthropogenic consumption within the basin but could also be due to long-term climatic change. Note that use of median annual flows may provide more useful information in situations where intra-annual variability is great, especially where there are large floods. These floods can mask the common flow situation. There are statistical approaches (e.g., student t-test) to measuring trends over time that should be applied to gain a better understanding of changes over time and whether they are significant. However, the 6.6.1 indicator has chosen to use just the last 5 years as compared to a natural reference flow, so the intervening trend is not used.

The strengths of direct streamflow monitoring as an indicator are that i) data are obtained directly from flow records with no need to model, ii) simple visualization of data which may be easily understood, iii) simple statistical analyses can be applied to determine if trends are real (statistically significant), iv) most countries have hydrometric networks so data can be easily updated annually (or 4 yearly), v) model results can be used where long records are missing; however the models need to take into account the anthropogenic changes within the catchment, and vi) by normalizing flow (i.e., dividing by the mean) it is possible to make inter-catchment comparisons.

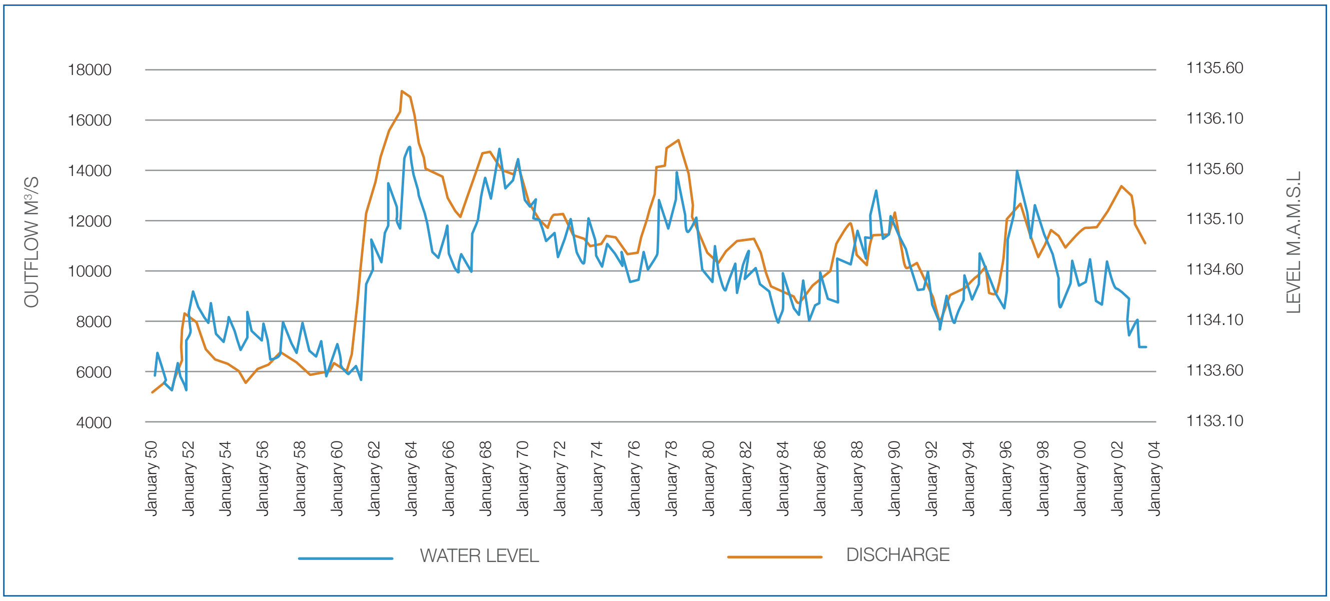
Weaknesses of this approach include the following facts: i) the changes measured may not necessarily be due to anthropogenic consumption and it requires a good understanding of what is happening in the basin to know the cause of change; ii) for rivers with highly variable flow it may be difficult to identify trends as statistical tests need many years of data; iii) making no allowance for any alteration to timing of flow or water quality both of which will impact aquatic ecosystems; and iv) long-term data sets (>20 years of data) may be hard to come by in some developing countries.

There is a move to model water availability using global data sets. In the future, it may be possible to access such data in an updated form from a global portal, but at present these models are not fully operational to provide this service. For example, the Global Runoff Database at GRDC[7] is a unique collection of river discharge data collected at daily or monthly intervals from more than 9,300 stations in 160 countries. This adds up to around 400,000 station-years with an average record length of 43 years. This repository may provide a good starting point for SDG reporting; however, it contains only data that originated from countries in the first place, which may, thus, not provide anything that the country does not already have. It would also not, in all likelihood, contain flow data for the most recent 5 years, representing the reporting period for SDGs.

There are also global models that help estimate streamflow and the impact of abstractions on water resources. For example, the WaterGAP global model[8] (Alcamo et al. 2003) is a hydrological (distributed) model that calculates the daily water balance in each grid cell (10 – 50 km grid sizes) either globally or for a country, a basin or a subbasin. For each grid cell, runoff is generated and routed by a global drainage direction map to the catchment outlet. This model has potential to be used for SDG 6.6.1 reporting at

[7] http://www.bafg.de/GRDC/EN/02_srvcs/21_tmsrs/riverdischarge_node.html
[8] https://www.uni-kassel.de/einrichtungen/en/cesr/research/projects/active/watergap.html

FIGURE 12. WATER LEVELS IN LAKE VICTORIA FROM 1950 TO 2004 (OKUNGU ET AL. N.D.).



the national and global scale but it will be necessary to check that the available data are appropriate for the SDG reporting period. There is an important caution to be considered when monitoring and reporting streamflow, especially where this is based on an annual mean as required by this 6.6.1 indicator; this caution is that it is the intra-annual flow variations which may be critical for proper ecosystem functioning. A useful example of where river flows are closely related to ecosystem requirements, specifically designed to incorporate seasonal fluctuations, is to be found in Brauman et al. (2016), who introduce an improved water-scarcity metric called water depletion. The Water Depletion model (Brauman et al. 2016) takes the WaterGAP outputs (Alcamo et al. 2003) and adds in those quantities of water which are ecologically significant and, thus, goes beyond simple change in flow over time. So, for example, while measurement of mean flow may suggest that a river is not substantially depleted, a single month in the dry season may be critically depleted thus having ecological and sustainability implications. One of the attractive aspects of this metric is that governments could use their own locally derived data and water budgets/models to produce a more accurate rendering of this water depletion metric. They define a series of biologically relevant hydrological attributes that characterize intra-annual variation in water conditions and then use an analysis of the inter-annual variation in these attributes as the foundation for comparing hydrologic regimes before and after developments. In this way, seasonal variations are included in long-term changes. The *"characterization of water depletion uses calculations from WaterGAP3 to assess long-term average annual consumed fraction of renewably available water, then integrates seasonal depletion and dry-year depletion, also based on WaterGAP3 calculations, with average annual depletion into a unified scale".* The output is a confident assessment of the depletion of water from the system over time and is thus useful for understanding the 6.6.1 Indicator. It would also be appropriate for use at the national scale where there is a need to interpret changes to the ecosystem and to assist with resource management.

4.4.2. Lake and reservoir volume

The change in the volume of water relative to the reference or natural condition will be calculated simply as a percentage change. The natural volume of a water body can be calculated by using records of the depth in historical times. At a minimum, the baseline of lake volume should be set at 2017, but where possible older references should be used.

By virtue of their greater volume, changes in lake volume generally take place at a slower rate than in rivers. Again, long-term data are needed to be able to establish proper trends, which for lakes can be a challenge, given the slow rate of change. For example, the water level of Lake Victoria in Africa, which has been monitored since 1896, has recently (over decades) gone through a large fluctuation in water level, partly due to abstractions, water releases for hydropower and catchment issues, but mostly due to climate variability (see Figure 12). Separating the drivers of change here, and in similar examples, is challenging and site-specific, which in the context of indicator 6.6.1 should be measured against natural reference conditions. Following such a determination, both a drop and an increase in volume will tell a story that will be useful for management towards sustainability. It may be that the change is driven by human-induced climate change or by an increase in abstractions, or it may be due to natural climate variability. Even if the reference volume is ultimately shown to be incorrect, the change in volume will tell its story.

For artificial reservoirs that are heavily impacted by abstractions, trends are difficult to measure as fluctuations can be due to abstraction and not due to rainfall and river inflow. For SDG reporting it is suggested that a 5-year moving average (mean) of reservoir volume will give a good indication of its overall status.

Measurement of lake volume can be carried out in many different ways, ranging from detailed bathymetric surveys to coarse approximations based on surrounding landform or even just the volume of an equivalent pyramid shape.

The simplest but effective measurement of lake volume (Taube 2000) is to determine average lake depth and multiply this by lake area. The average depth is obtained by averaging depth soundings, which for a reliable average, should be spaced in a uniform grid pattern. This is multiplied by surface area to establish the volume. The greater the number of depth measurements, the greater the confidence in the result, which again should be determined by the needs of the country. The omission of depth soundings for very shallow water (e.g. close to shore) is a common source of error in the application of this method, as a small rise in water level may reflect a very large increase in volume. Over time, by reading the changes in water level from a gauge plate, or from EO data, changes in volume can be estimated. Thus, the main cost of this measurement is in the initial setup that describes the lake floor. Note that if a lake is subject to large inputs of sediment, then more frequent measurements of the inflow portion of the lake (such sediments rarely travel far into a lake) should be carried out.

A more accurate formula for calculation of lake volume is given by Taube (2000).

$$V=0.5H\times(A_1+A_2)$$

where, V = volume of water, H = difference in depth between two successive depth contours, A_1 = area of the lake within the outer depth contour (i.e., shallower) being considered and A_2 = area of the lake within the inner contour line (i.e., deeper) under consideration.

The procedure consists of determining the volumes of successive layers of water (frustums), and then summing these volumes to obtain the total volume of the lake. Hollister (2010) documented a simple GIS approach for estimating lake volume using limited data. He uses GIS to model bathymetry and estimate the volume of a lake with only maximum depth and a lake shoreline layer. Using a simple linear transformation, he estimates depth as a function of distance from shoreline and then calculates the lake volume. There are also options for EO approaches to estimating lake volume (Magome et al. 2003).

4.4.3. Groundwater depth/volume

This method is based on estimating volumes of groundwater storage in aquifers. This means that for the reference situation an estimation will need to be made of the total available volumes of groundwater in a country. Once that has been established then changes in volume can be calculated based on changes in groundwater levels.

S: Storativity (also known as Storage Coefficient) is the volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit area of the aquifer. *S* is a dimensionless quantity and ranges between 0 and the effective porosity of the aquifer.

If local data on storativity values of the aquifers are available then these should be used. If no such data are available then values from literature can be used (see Table 10, below).

The storativity of a confined aquifer typically ranges from 5×10^{-5} to 5×10^{-3}; in unconfined aquifers, storativity typically ranges from 0.1 to 0.3. See Table 10 for representative values for various aquifer materials. For confined aquifers, storativity is calculated by multiplying the aquifer thickness (b) with the aquifer's Specific Storage (S_S).

Long-term monitoring of groundwater levels. As a minimum, the baseline of 2017 will be used as a future reference and it will only be over time that the real trajectory of change will become clear.

4.5. Setting targets

In the past, setting a target for the discharge of a river was generally done when there were users with a particular

Changes in (national) groundwater storage should be given as a fraction of the reference (national) groundwater storage. For a country with *n* aquifers considered:

$$\text{Indicator 6.6.1.b (\%)} \quad \frac{\Delta V_{aq1} + \Delta V_{aq2} + \cdots + \Delta V_{aqn}}{V_{aq1}^{ref} + V_{aq2}^{ref} + \cdots + V_{aqn}^{ref}} \times 100 \qquad [5]$$

Where: [6]

$\Delta V = A\times\Delta h\times S$

$V^{ref} = A\times b\times S$ [7]

Where:

A: aquifer areal extent

b: average/mean saturated aquifer thickness

S: Storativity / storage coeffient (see below)

Δh: average/mean change in hydraulic head (average change in groundwater level measured in monitoring wells)

Ref: reference situation (either the 'natural situation or the reference year 2016/2017)

TABLE 10. STORATIVITY VALUES FOR DIFFERENT AQUIFER MATERIAL.

MATERIAL	STORATIVITY	
UNCONFINED AQUIFERS		
Gravel, coarse	0.21	
Gravel, medium	0.24	
Gravel, fine	0.28	
Sand, coarse	0.30	
Sand, medium	0.32	
Sand, fine	0.33	
Silt	0.20	
Clay	0.60	
Sandstone, fine grained	0.21	
Sandstone, medium grained	0.27	
Limestone	0.14	
Dune sand	0.38	
Loess	0.18	
Peat	0.44	
Schist	0.26	
Siltstone	0.12	
Till, predominantly silt	0.60	
Till, predominantly sand	0.16	
Till, predominantly gravel	0.16	
Tuff	0.21	
CONFINED AQUIFERS	**MIN**	**MAX**
Plastic clay	b x 2.56 x 10-3	b x 2.03 x 10-2
Stiff clay	b x 1.28 x 10-3	b x 2.56 x 10-3
Medium hard clay	b x 9.19 x 10-4	b x 1.28 x 10-3
Loose sand	b x 4.92 x 10-4	b x 1.02 x 10-3
Dense sand	b x 1.28 x 10-4	b x 2.03 x 10-4
Dense sandy gravel	b x 4.92 x 10-5	b x 1.02 x 10-4
Fissured rock	b x 3.28 x 10-6	b x 6.89 x 10-5
Sound rock	< b x 3.28 x 10-6	
	where b = aquifer thickness	

demand for water that had to be met. Coarse estimates were sometimes made on how much water should remain in the river, but the world abounds with situations where water has been withdrawn to the point where there is no water left. These river ecosystems are thus reduced to a highly degraded state. However, over the past two decades there is a new perspective that has come to be recognized the world over, and that is of the environmental flow requirements, or environmental water requirements, or E-flows, of a river system. Environmental flows are *"the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems"* (The Brisbane Declaration 2007). There are numerous review papers on the subject including those by Dyson et al. (2003), Acreman and Dunbar (2004) and Poff and Matthews (2013).

Many countries of the world are already using an estimate of the environmental flows to set targets for their rivers, and in many cases for floodplains, vegetated wetland, lakes and even groundwater. A useful review of the implementation challenge is that by Le Quesne et al. (2010). In the policy of many countries, this now forms the top priority for any allocation of water, sometimes on a par with the provision of basic human needs, and before other (uses) can be considered.

Environmental flow requirements are a component of SDG indicator 6.4.2 (*Level of water stress: Freshwater withdrawal as a percentage of available freshwater resources*), and so are not reproduced in the 6.6.1 method; however they remain an important part of the context of streamflow management. While indicator 6.6.1 reports on the volumes of water in ecosystems, it does require that countries set targets, and that these targets should take environmental flows into consideration. This should also seek to comply with Aichi Biodiversity Target 5 which promotes that habitat loss is reduced to zero (or at least to half), and Target 14 that essential ecosystems are restored and safeguarded (Aichi Targets were adopted by countries signing the Convention on Biological Diversity or CBD).

The key challenges for setting of environmental flows as targets for a country, are:

- The percentage of water that should be allocated to environmental flows is variable per ecosystem, per river reach, and should change over the seasons as there will be different environmental requirements for dry vs. wet seasons.
- It is necessary for society to establish a vision for a water body before a decision can be made on which environmental flow to allocate. If society decides that a particular river reach is contributing to conservation (a Class A or B), then the E-flows will be higher than if a river reach is considered as a "hard working" river (Class D or D), that it is located, for example, below a city where it needs to dilute wastewater discharges. Thus E-flows will be different in terms of the Class set for each particular water body (see Table 5 for a description of these classes).

Thus, setting a target for water volume in a water body requires an understanding of those users who need access to the water resource, balanced by the environmental water requirements of that same water resource.

5. SUB-INDICATOR 6.6.1.C: PERCENTAGE CHANGE IN WATER QUALITY

Water quality is derived from indicator 6.3.2: Percentage of water bodies with good ambient water quality.

Water quality, along with quantity, are possibly the two greatest drivers of ecosystem response and are, thus, important for understanding the situation of all water-related ecosystems. The details of this method are presented in indicator 6.3.2, and the final result of such a report is simply carried over for inclusion in the 6.6.1 aggregated score. However, there is a small conversion of the data that is required. While the 6.3.2 score represents the data as a percentage compliance for a single river basin, e.g., 93% compliance in "good" condition, SDG 6.6.1.c requires this to be converted to percent change from natural. Thus a 93% compliance that is reported by the 6.3.2 method becomes a 7% change from natural in the 6.6.1.c indicator. The following information about the basic-level monitoring is copied from the 6.3.2 method. At the basic level, five parameters have been selected to determine water quality, but options are given for more comprehensive monitoring, where appropriate. The parameters included in 6.3.2 monitoring and thus which contribute to the calculation of the 6.6.1 score are the following:

- Dissolved Oxygen
- Electrical conductivity
- pH
- Orthophosphate
- Total Oxidized Nitrogen

The reasons for inclusion of these core parameters are given below and are extracted from the 6.3.2 method.

Dissolved Oxygen (DO) is important for aquatic organisms. Levels of DO fluctuate naturally with temperature and salinity. Turbulence at the surface of a river, at riffles or at waterfalls can increase DO concentrations. Photosynthetic activity of aquatic flora and respiration by aquatic organisms can also affect concentrations diurnally and seasonally. Very low oxygen concentrations may suggest the presence of biodegradable organic matter, such as sewage. Ideally, DO is measured *in situ* using an oxygen probe, but methods are available where the oxygen in the water sample is chemically fixed for analysis in the laboratory.

Electrical Conductivity (EC) is a simple measure of dissolved substances, such as salts, that help characterize the waterbody. Values of EC change naturally, especially during periods of increased flow. The inclusion of EC as a core parameter is due to its simplicity of measurement and because deviation from normal ranges can be used as an indicator of pollution, such as wastewater inputs to the waterbody. The most accurate method to measure EC is using a conductivity meter *in situ*, because values can change during the time between collection in the field and analysis in the laboratory.

pH is included as a core parameter because, like EC, it is useful to help characterize the waterbody. pH is one of the most widely measured parameters due to its influence on many biological and chemical processes. It is a measure of the activity of the hydrogen ion in the water which can fluctuate naturally, especially with changing hydrological conditions as the composition of the water at the sample site changes between groundwater, subsurface flows and surface runoff during rain events. Changes outside of natural ranges indicate possible pollution from industrial or other wastewater sources. pH is most accurately measured *in situ* using a potentiometric probe because values can change during the time between collection in the field and analysis in the laboratory.

Orthophosphate (OP) is a bioavailable dissolved inorganic form of phosphorus which is an essential nutrient for aquatic life. Additional inputs from human activities, such as wastewater or agricultural runoff, can increase concentrations such that they support excessive plant growth which affects the balance of the aquatic ecosystem and impairs water quality for human uses. Orthophosphate can be measured in the field using test kits, but the greatest accuracy and limits of detection are achieved in the laboratory. OP concentrations can change over time if the sample is not fixed and therefore it is suggested that samples are analyzed within 24 hours.

Total Oxidized Nitrogen (TON) is a combined measure of both nitrate and nitrite which are forms of dissolved inorganic oxidized nitrogen. Like phosphorus, nitrogen is a nutrient essential for aquatic life where additional inputs can have detrimental impacts on freshwater ecosystems. Total Oxidized Nitrogen, rather than nitrate, is suggested because the analytical method is more straightforward and does not require the reduction step needed to measure nitrate alone. In most instances, the nitrite fraction of TON in surface waters comprises less than 1% of the total, so that for practical purposes, TON and nitrate are the same. As with OP there are kits available for *in situ* monitoring of TON.

It could be argued that for water-quality monitoring and reporting, the above may seem like a deficient list with which to evaluate the quality of an ecosystem. However, for a global indicator, this represents a good step that gives a generic indication of ambient water quality that should be within the means of most countries. The 6.3.2 method gives guidance on additional monitoring that can be undertaken, which should be ideally implemented where there is a need or where particular conditions are anticipated. It is important that no country should just take the above five component water quality indicator results at face value, but should consider the real issues threatening an ecosystem and should temper any conclusions that are made. For example, there are places where the main problem with the water quality in an ecosystem is, for example, pollution with heavy metal from a mine, or pesticide, which would not be reflected in the basic 6.3.2 result. It is important that the country temper a potentially "good" result suggested by the 6.3.2 indicator, with data and comments about additional variables.

6. SUB-INDICATOR 6.6.1.D: PERCENTAGE CHANGE IN HEALTH/STATE OF ECOSYSTEMS

6.1. Scope

Note that for the 2017 baseline reporting period it is not required to submit results on indicator 6.6.1.d. The main reason for this was that these methods are, to some extent, locally specific (determined by the nature of local ecosystems) and also that many countries are not in a position to report. However, there are many countries that do implement such monitoring, so it is envisaged that this sub-indicator will be included in the next reporting period so that countries are advised to begin with data collection.

What is ecosystem health? This term is increasingly being adopted by agencies around the world because of its intuitive meaning. Costanza and Mageau (1999) defined a healthy ecosystem as *"one that is sustainable – that is, it has the ability to maintain its structure (organization) and function (vigour) over time in the face of external stress (resilience)".* This is generally considered to be similar to the concept of state of the ecosystem and it is taken that these two terms can be used interchangeably.

There are many ways to determine the health or state of water-related ecosystems and indeed many countries and regions have formal programs to do so (e.g., European Water Framework Directive, Australian National River Health Programme, South African River Health Programme, USA National Rivers and Stream Assessment of the US EPA, Mekong River Commission Ecological Health Monitoring – see examples later on in this section). Most of these programs are based on the *response* of the ecosystem to *drivers* of change. Thus, for example, assessing the state of the macroinvertebrates in the ecosystem may give an indication of the overall impact of all the drivers that have an effect on the macroinvertebrates. These include water quality and quantity, the flow regime, the impact of anthropogenic use etc. Monitoring the response of the ecosystem is thus a direct measurement of ecosystem health or state.

Ecosystem health monitoring procedures are generally site-based i.e. data are collected by field visits to a site of interest. They provide a direct measure of the state or health of water-related ecosystems even though interpretation of the causes of any degradation may not be clear. Monitoring of ecosystem health using EO is a rapidly advancing technology that may in the future provide data to more accurately assess ecosystem health at a global level. At present EO methods provide only a rough indication, possibly best reserved for the identification of "hot spots" that need to be verified on the ground.

This indicator method does not prescribe any particular method for measurement of the health of water-related ecosystems because most of the existing methods are based on local ecological conditions that are not applicable at a global level. Also, the methods appropriate, for example, to palustrine wetlands, rivers and mangroves, etc., are all different and cannot be used interchangeably between different ecosystems. Furthermore, a method that may work in a northern temperate zone would be different from a method appropriate for a tropical zone. And lastly, within a region there may be methods that make use of the benthic aquatic invertebrates, for example, which will produce complimentary but different results to an assessment based on fish or riparian vegetation. *To make it possible to* *utilize these varied methods, this indicator requires that for whichever method is used, the measurement of the present situation needs to be compared to the Natural Reference condition as a percentage of change.*

A key ecosystem health indicator uses indices of aquatic macroinvertebrate populations in rivers, as these organisms respond to changing quantity and quality of water in a way that can be predicted and measured. Fish diversity and populations also change in relation to stresses on the system, giving a direct measure of the impact of those stresses. Additional methods are described below.

Figure 13 illustrates the relationship between the drivers of river health and the end point of the ecosystem process as the biological response. This figure demonstrates the value of monitoring the end point of the process (i.e., the biological response), as this represents the culmination of all the ecological processes and is thus most suited to representing the whole of Target 6.6.
Iversen et al. (2000) coined the phrase of "EcoStatus" to describe this end point, and defined it as "The totality of the features and characteristics of the river and its riparian areas that bear upon its ability to support an appropriate natural flora and fauna and its capacity to provide a variety of goods and services".

Those methods suited to the country for application are recommended to be used. Example sources of information include:

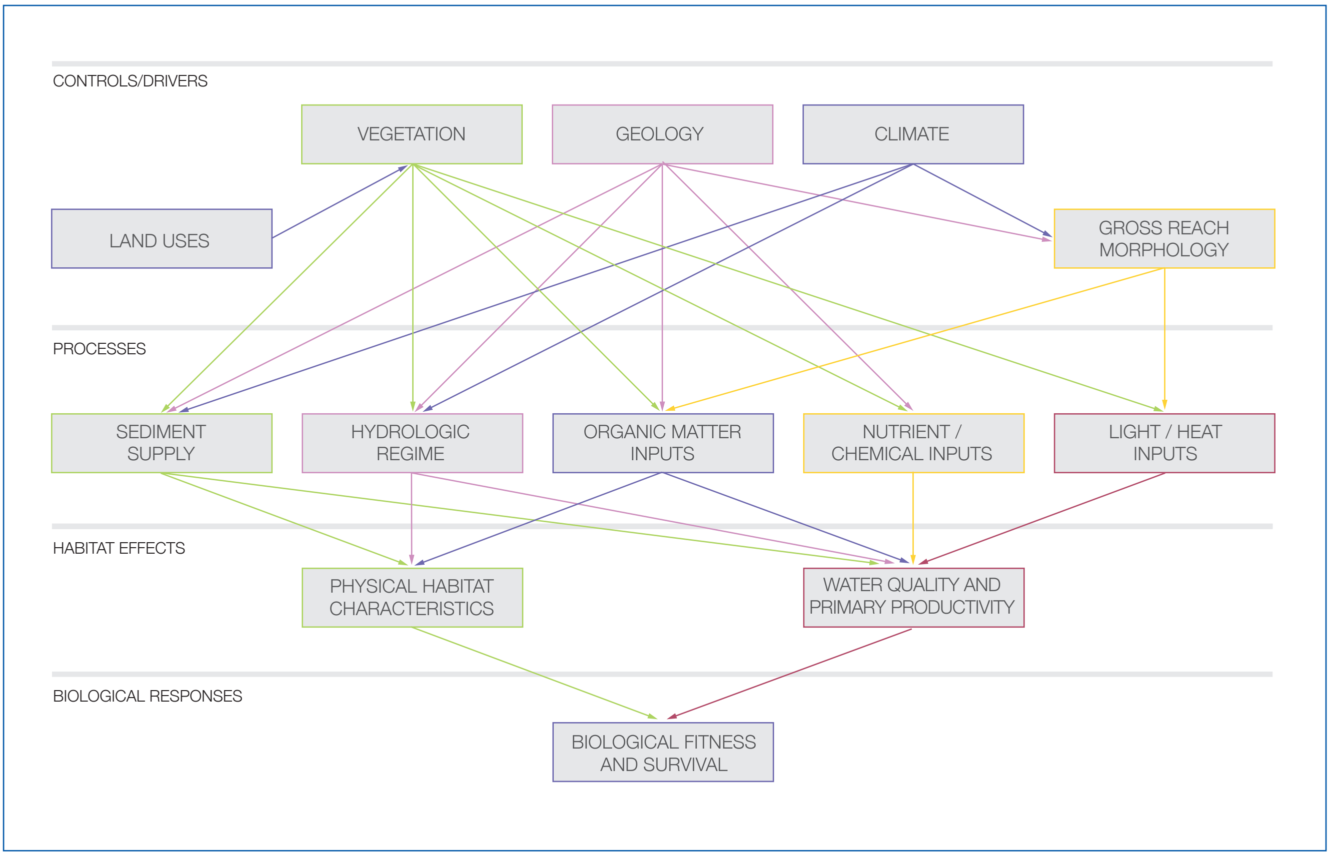
- US EPA - https://www.epa.gov/national-aquatic-resource-surveys/nrsa
- Australian River Assessment System AusRivAS - http://ausrivas.ewater.org.au/
- South African River Health Programme - http://www.dwa.gov.za/iwqs/rhp/default.aspx
- European Water Framework Directive - http://www.wfduk.org/resources/category/biological-standard-methods-201
- Ramsar Convention on Wetlands http://www.ramsar.org/resources/ramsar-handbooks-and-manual

6.2. Source and collection of data

6.2.1. Earth Observation for monitoring the health of water-related ecosystems

While most of the methods for assessment of ecosystem health are ground-based, the one method potentially available for wide-scale assessment using EO is to make use of vegetation indices perhaps joined with measurement of soil moisture and open water bodies. While there are existing methods that serve this purpose, their results may be spurious as they give no indication

FIGURE 13. SCHEMATIC DIAGRAM OF RELATIONSHIPS BETWEEN CONTROLS ON CATCHMENT PROCESSES, EFFECTS ON HABITAT CONDITIONS, AND AQUATIC BIOTA SURVIVAL AND FITNESS



SOURCE: (adapted by Kleynhans and Louw, 2008 from Beechie and Bolton, 1999 of the kind of vegetation that is present and, thus, no indication of the ecological condition of the water-related ecosystem. However, it is anticipated that appropriate methods will soon become available in which case they will form a valuable part of monitoring this sub-indicator.

6.2.2. Ground-based methods for monitoring the health of water-related ecosystems

Possible methods for this sub-indicator of change in the health of water-related ecosystems could include:

- *Habitat integrity* – This represents only the habitat without the final inclusion of the biological response. Several such methods exist including Tiner (2002) for the USA which considers the possibility of EO techniques to assess watershed habitats.
- *Fish condition indices* – There are many such indices which include either or all the community and population statistics, species diversity, size classes and physiological health of individual fish. Examples of fish indices include the Index of Biotic Integrity of the USA (USEPA 2007) and Kleynhans (2007).
- *Benthic macroinvertebrate indices* – These invertebrates have been used in most countries as a form of biomonitoring in particular rivers. The advantage of these indices is that the invertebrates are common and widespread, easy to collect, and the different families/species indicate the quality of the water and habitat availability. Examples include the SASS index (Dickens and Graham 2002) for South Africa, SIGNAL (Chessman 2003) for Australia, and Wright et al. (2000) with the RIVPACS model for the UK.
- *Diatoms* are used in a wide range of water ecosystems to indicate conditions of water quality. The advantage of this method is that diatoms are generally ubiquitous and common, with limited global diversity. The different diatom species respond differently to different perturbations, and are, thus, ideally suited as indicators of water quality. The negative is that the method requires a high level of skill to implement. Examples include CEN (2003) for Europe, and Taylor et al. (2007) for South Africa.
- *Vegetation* is a key aspect of most water-related ecosystems. Vegetation provides both a response to the prevailing wet conditions, and is also a driver that impacts on other biota that will subsequently develop in the system. Vegetation monitoring is most useful for those ecosystem types where it is a dominant part of the ecosystem, e.g., palustrine wetlands, floodplains, etc. It is less useful for lentic systems such as lakes, and for rivers which tell a story of the ecosystem that is only a partial reflection of the health or state of the instream river. Riparian vegetation is subject to several other stresses from land-based activities that bare no relation to the instream condition. There are many different riparian vegetation methods but there is considerable variation in the approach of these methods. Possibly the most useful types of vegetation methods for SDG monitoring are those that categorize the vegetation into classes illustrating vegetation cover, density, recruitment, etc.
- *Wetland health indices* – There are several indices that have been developed that utilize the vegetation and other hydro-geomorphic characteristics of wetlands (generally of palustrine wetlands) to determine the health. The Water Research Commission in South Africa (www.wrc.org.za) has published extensively on these.
- *Lake health indices* – Traditionally, these indices have been measured by a simple Secchi depth measurement which indicates the clarity of the water, and also the measurement of chlorophyll concentrations which indicate the extent of algal growth and, thus, of eutrophication. Other more complex indicators consider the species of phytoplankton as well as water chemistry.
- *Groundwater ecological indicators* – The most relevant ecological indicator for groundwater is the interaction that the groundwater has with the surface water. This includes the provision of baseflow into the river especially during the dry season and also the extent of groundwater that is close to the surface and accessible to tree or other plant roots.

The guidelines for each method need to be followed during implementation. Any method used should have been subject to peer review in the literature, or should be the standard method of an implementing agent or authority.

Frequency of monitoring will differ depending on the ecosystem and the component of the ecosystem being monitored. Thus, for example, benthic macroinvertebrates in a river may change with some rapidity (hours to be destroyed, but weeks/months to recover) in response to changing water conditions. Fish take longer to recover following a major incident (months to years) while riparian vegetation generally would only reflect major changes over several years. However, for SDG monitoring, the aim is not to detect short-term changes that may occur as a result of short-term impacts on the ecosystem, but rather longer-term trends. Hence, the frequency will be determined to obtain statistical reliability, to "smooth out" seasonal and other sources of variability, and to determine the long-term trend.

6.2.3. Scale and frequency of monitoring

Ecosystem health is generally monitored at a local level as many aquatic systems (e.g., wetlands and rivers) have the capacity to self-regenerate over distance and over time. Generally, sites are used for monitoring. With careful interpretation, these results may be extrapolated to a larger area where there are no additional human influences, and in this way data can be reproduced for longer reaches of river length. The location of sites may be upstream and/or downstream of the location of human-induced stress, which then provides information on the extent of change due to that human influence which in turn facilitates better management. Aggregation of this data to a basin level is fraught with uncertainty and may be misleading where there are local impacts not reflected across the entire basin.

Natural ecosystems change over the seasons as part of their natural cycles so that monitoring of ecosystem health can yield different results in these different seasons. While in some situations monitoring during the wet season can give spurious results due to the inundation of habitats, monitoring in the dry season may equally give spurious results in an ephemeral system. Careful consideration thus needs to be given to the appropriate frequency and also time of year for sampling, which should be selected to ensure the objectives of this monitoring the change in ecosystem health over time are achieved. Monitoring at a regular time of the year, in some situations just before the onset of the wet season often provides the most revealing results. Seasonal sampling can allow for greater understanding of complex ecological systems. In cases where monitoring procedures are complex and also where the response time of the ecosystem to changes in the drivers is very slow, 5 yearly or even less-frequent surveys may be appropriate. An example of this would be the health of fish populations (five yearly in large rivers) or of riparian vegetation which may respond even more slowly and will continue to respond to a hydrological change for decades.

6.3. Representation of data and results

The many and varied methods for estimation of ecosystem health generally have different reporting requirements but for the 6.6.1 indicator reporting, it is important that all results are normalized by converting them to a percentage change from the natural condition. This information can be reported for a site, or extrapolated to represent a system or even basin if there are no additional sources of stress in the system that were not included in the sample result.

There are many country reports that show how such data and information can be presented, some of which are noted in section 6.1.

6.4. Setting a target

The Ecological Classes as presented in Table 5 are important for representation of this indicator result. The deviation of the ecological health from the natural condition is the only reasonable way of presenting this result which makes it possible to use almost any locally relevant method to represent the health of the system.

At a global level, as noted by the indicator 6.6.1 method document (GEMI 2017), the global ambition is to protect and restore ecosystems. At the country level, targets for the health or state of ecosystems should be established for key rivers, lakes and for priority wetlands based on priorities in the country. It will be necessary for countries to classify their ecosystems to identify those that need protection and to what Class (Table 5) that protection should be given, although many countries will choose to include all significant water resources in this monitoring. There will also be those ecosystems that need to be restored to achieve the required Class.

In the absence of any classification of ecosystems, as a precautionary approach, a country should adopt a target of “no reduction of the 2017 baseline”, and a Class D (Table 5) should be the minimum that is accepted for any ecosystem. The Aichi Biodiversity Targets (Convention on Biological Diversity that most countries are signatory to) provide added incentive to set these targets, as Target 5 promotes that habitat loss is reduced to almost zero, and Target 14 states that essential ecosystems are restored and safeguarded.

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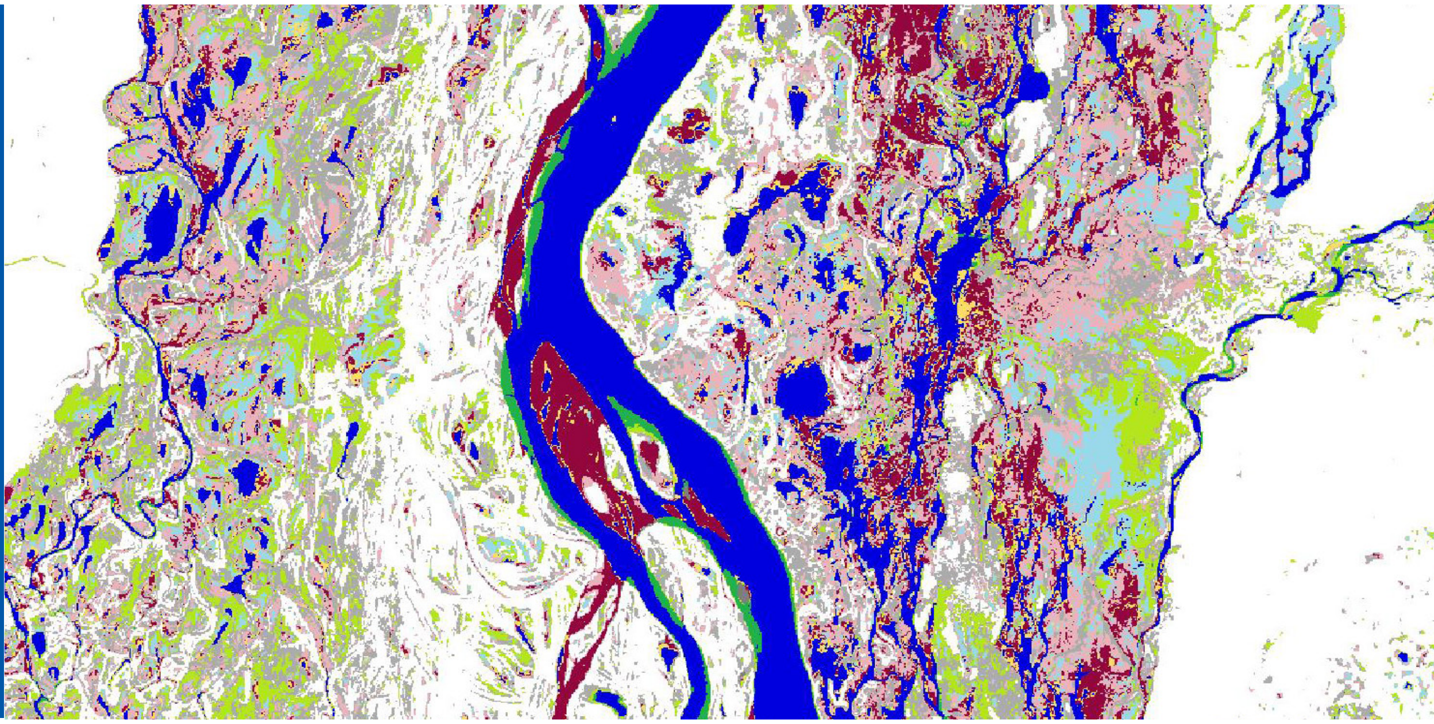

Changes over time of open water: The Parana River in Argentina. Reproduced from Pekel et al. (2016)

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