MONITORING METHODOLOGY FOR SDG INDICATOR 6.6.1

INTRODUCTION TO INDICATOR 6.6.1

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**

Water-related ecosystems provide important social and economic benefits to societies, such as provision of drinking water and sanitation, recreational opportunities, maintenance of aquatic habitats to support biodiversity and fishery industries, water for key sectors such as energy and agriculture, and regulation of water flows. To ensure these important services to society are sustained, water-related ecosystems must be both protected and restored. Target 6.6 aims to do this, using the imminent date of 2020 in order to align with the Aichi Biodiversity Targets of the Convention on Biological Diversity, but will continue beyond that date to align with the rest of the SDG Targets set at 2030.

Indicator 6.6.1 is the only indicator under Target 6.6 and thus accurate and comprehensive reporting on this indicator is vital for guiding action towards rapid progress of the Target. This Indicator tracks changes over time in the extent of water-related ecosystems. Indicator 6.6.1 enables countries to monitor progress towards achieving Target 6.6, in particular the protection and restoration of vegetated wetlands, open water, rivers and aquifers, all of which are known to play an important role in the delivery of water-related services. Due to the multi-faceted nature of Indicator 6.6.1, a progressive methodology is proposed which promotes country-derived data collection to be complimented by other globally available datasets such as earth observations. Used in conjunction with national knowledge and data, global earth observations which are validated by countries can enhance an understanding of how and why water related-ecosystems are changing.

This Indicator aims to collect and provide data on the spatial extent of water-related ecosystems and the quantity and quality of water within them. In combination, these components provide a comprehensive picture that enables informed decisions towards the protection and restoration of these ecosystems. The Indicator 6.6.1 data monitored on water-related ecosystems also enables decision-makers to prioritize ecosystem health, or the ability of ecosystems to maintain their structure and function over time in the face of external pressures. Some ecosystems are not included in Indicator 6.6.1 such as coral reefs which are covered in Goal 14; and mountains, forests, and drylands which are covered in Goal 15.

The following definitions describe Indicator 6.6.1 for the purposes of global monitoring:

Water-related ecosystems – includes five categories: 1) vegetated wetlands, 2) rivers and estuaries, 3) lakes, 4) aquifers, and 5) artificial waterbodies. For purposes of this methodology, the text refers only to these five ecosystem category terminologies. The majority of water-related ecosystem types monitored in Indicator 6.6.1 contain freshwater, with the exception of mangroves and estuaries which contain brackish waters and are included in Indicator 6.6.1. Ecosystems containing or within salt waters are not included as these are covered within other

SDG indicators (Goal 14). Other categories of wetlands aligning with the Ramsar Convention definitions are captured within the ecosystem category of ‘vegetated wetlands’.

Vegetated Wetlands – the water-related ecosystem category of vegetated wetlands includes swamps, fens, peatlands, marshes, paddies, and mangroves. This definition is closely related to the Ramsar Convention on Wetlands definition of wetlands, which 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 metres” with the exception that salt waters are *not* included in Indicator 6.6.1 reporting (as they are covered in SDG 14) and with the exception that vegetated wetlands are distinct from the other ecosystem categories of lakes, rivers and estuaries, aquifers, and artificial waterbodies. Vegetated wetlands have been separated as their own ecosystem category because of their importance for target achievement and because the methodology for monitoring them with earth observations is unique from other open waters. The data generated by applying this methodology will also generate data required by countries to report to the Ramsar Convention on Wetlands.

Artificial Waterbodies – the water-related ecosystem category of artificial waterbodies includes open waterbodies created by humans such as reservoirs, canals, mines and quarries. While it is recognized that these are not traditional water ecosystems which should be protected and restored, in some countries they hold a noteworthy amount of freshwater and have thus been included.

Open Water – as any area of surface water unobstructed by aquatic vegetation. This includes the following 3 water-related ecosystem categories: rivers and estuaries, lakes, and artificial waterbodies.

Extent – has been expanded beyond spatial extent to capture additional basic parameters needed for the protection and restoration of water-related ecosystems. Extent includes three components: the spatial extent or surface area, the quality, and the quantity of water-related ecosystems.

Change – a shift from one condition of extent to another over time within a water-related ecosystem, measured against a point of reference.

It is important to note that not all components of extent are relevant for all types of water-related ecosystems. For example, monitoring water *quantity* within vegetated wetlands or the *spatial extent* of aquifers is not an accurate measure of their state and therefore is not included in this monitoring methodology. Similarly, monitoring of water *quantity* of lakes and artificial waterbodies is also not included because changes in the *quantity* of these ecosystems can be inferred by measuring their *spatial extent* using earth observations. This is a more resource-efficient measurement approach and reduces reporting burden on countries. Table 1 summarizes which component of extent is applicable for each ecosystem category.

Table 1 Water-related Ecosystem Categories and their Applicable Extent Components

		Water-related Ecosystem Categories				
		Lakes	Rivers and Estuaries	Vegetated Wetlands	Aquifers	Artificial Waterbodies
Extent Components	Spatial Extent	▨	▨	▨	N/A	▨
	Quality	▨	▨	▨	▨	▨
	Quantity	N/A	▨	N/A	▨	N/A

N/A = No requirement to monitor for Indicator 6.6.1

PROGRESSIVE MONITORING APPROACH

Agenda 2030 is a country-led and country-owned process, and this methodology embraces this approach which places responsibility on countries to monitor and report data on all SDG indicators. The environmental dimension of the SDG indicators is relatively new compared to the MDGs and nationally-derived environmental data has not often been captured before. With this in mind, this methodology encourages the use of globally available environmental data to enhance country-derived data, filling data gaps and enabling countries to more rapidly make progress towards achieving Target 6.6. This same approach has been adopted for other SDG Indicator methodologies, such as Indicator 15.3.1.

This methodology applies a progressive monitoring approach meaning countries can utilize both globally- and nationally- derived data to report on Indicator 6.6.1. Global data must be owned and validated nationally to comply with the intention of Agenda 2030. Countries should aim to report on all aspects of Indicator 6.6.1 should they have the data and capacity to do so. While it is beneficial to capture data on all aspects of the Indicator, some countries may be able to achieve this and others may not have all data available. This progressive monitoring approach therefore encourages different levels of ambition.

The progressive monitoring approach uses 2 Levels and 5 Sub-Indicators. The pilot testing in 2017 revealed that countries currently lack capacity to monitor all 5 Sub-Indicators of Indicator 6.6.1. Thus, Level 1 data utilizes data which is already globally available to establish a foundation which can be strengthened by countries as they develop capacity and ability to report on Level 2 data. **All globally available data will be shared with national statistical offices and other relevant authorities for in-country validation, to ensure the water-related ecosystems are represented accurately.** Since this global data is derived from earth observations, some countries may have and return their own earth observations of even higher resolution and accuracy which will then be used.

Level 1 includes 2 Sub-Indicators based on globally available data from earth observations which will be validated by countries against their own methodologies and datasets:

- Sub-Indicator 1 – spatial extent of water-related ecosystems
- Sub-Indicator 2 – water quality of lakes and artificial water bodies

Level 2 data is additional data informing progress on target 6.6 collected by countries. This data may already be available and reported under existing monitoring mechanisms. Countries are encouraged to consolidate this data in order to better understand the state of their freshwater ecosystems and which actions to take. Level 2 data includes the following 3 Sub-Indicators:

- Sub-Indicator 3 – quantity of water (discharge) in rivers and estuaries
- Sub-Indicator 4 – water quality imported from SDG Indicator 6.3.2
- Sub-Indicator 5 – quantity of groundwater within aquifers

A progressive monitoring approach is beneficial because it prioritizes components of the Indicator where high-quality data is widely available, reducing the reporting burden on countries and focusing monitoring efforts on validating Level 1 data and generating Level 2 data. These focused monitoring efforts will be supported by increased capacity-building, technological advancements, and improved data sharing among the international community (Figure 1).

It is also essential to monitor how the health of water-related ecosystems is changing. However, health has not been included as a formal Sub-Indicator for Indicator 6.6.1 because monitoring ecosystem health is context-specific and the most appropriate methodology is based on local ecological conditions. It is recommended that countries with the capacity to monitor ecosystem health take advantage of the data generated for each of the 5 Sub-Indicators, which can be used in combination with *in situ* country data, such as bio-indicators, to inform the state of water-related ecosystem health.

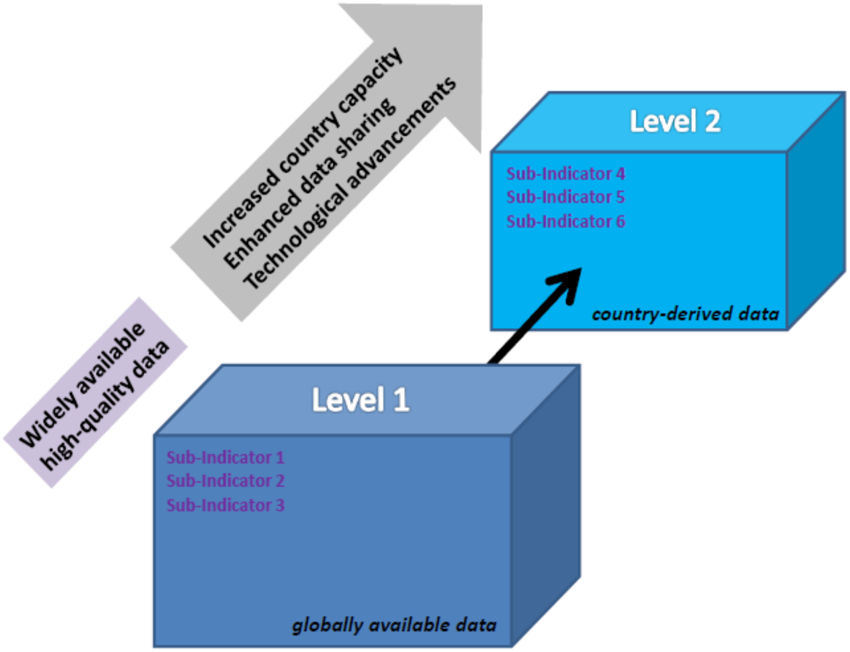

Figure 1 Indicator 6.6.1 Progressive Monitoring Approach

LEVEL 1 DATA: METHODOLOGY FOR MONITORING AND REPORTING

This section provides the methodology for monitoring and reporting on Level 1 data. Level 1 data is divided into two Sub-Indicators: spatial extent of water-related ecosystems (Sub-Indicator 1); and water quality (Sub-Indicator 2).

SUB-INDICATOR 1

SPATIAL EXTENT OF WATER-RELATED ECOSYSTEMS

Sub-Indicator 1 includes two separate methodological approaches:

- Spatial extent of 'open water' – lakes, rivers, estuaries, and artificial waterbodies
- Spatial extent of vegetated wetlands

Two distinct methodological approaches are required in order to distinguish and generate spatial extent data on open water and specifically on vegetated wetlands. The data generated on open water is further distinguished into lakes, rivers and estuaries versus artificial waterbodies. The resulting datasets obtained from earth observations on the spatial extent of vegetated wetlands and artificial waterbodies are excluded from the calculation of spatial extent values for lakes, rivers and estuaries, to prevent duplication of spatial extent estimations.

Earth observations distinguish types of land cover, one of which is water. The surface area of water (i.e. its spatial extent) is frequently captured providing an accurate delineation of where permanent water is located on the surface of the earth. In this sense, 'permanent water' incorporates seasonal and climactic changes from year to year. From here, the spatial extent of lakes, rivers, estuaries and artificial waterbodies can be calculated. Earth observations can also monitor spatial extent of vegetated wetlands by utilizing datasets such as land cover, elevation, vegetation cover and soil moisture. As defined in Section 1, Indicator 6.6.1 water-related ecosystems are defined as ecosystems containing freshwater and brackish water (thus excluding salt waters) so any global earth observations results will only include fresh and brackish waters.

Established intergovernmental expert groups such as the Group on Earth Observations (GEO) and the Global Geospatial Information Management Group (GGIM) (comprised of United Nations Member States and partnered with National Statistical Offices (NSOs) and international agencies) have informed the design of this Sub-Indicator 1 methodology, including how data is generated, its source(s), and the spatial and temporal resolution.

All geospatial data generated is subject to validation by national authorities, as it is recognized that existing ground data may exist in countries on the spatial extent of their water-related ecosystems. Some countries are also already using earth observations to monitor spatial extent of water-related ecosystems. In such instances, all spatial extent geospatial data collected on behalf of countries will be shared to facilitate the formulation of the most accurate spatial extent estimate of a country's water-related ecosystems.

SPATIAL EXTENT OF LAKES, RIVERS AND ESTUARIES

This section includes the methodology for monitoring the spatial extent of two of the five defined ecosystem categories: lakes, and rivers and estuaries. Of note, when data is generated for these two ecosystem categories, the spatial extent of artificial waterbodies and some vegetated wetlands may also be captured. Artificial waterbody and vegetated wetland spatial extents will be excluded from this part of the assessment so that the four ecosystem category datasets are discrete.

Generating Spatial Extent Data on Lakes, Rivers and Estuaries from Satellite Imagery

The spatial extent of open water bodies can be collected using satellite imagery. The basic premise of this approach is that different land covers, such as snow, bare rock, vegetation, and water, reflect different wavelengths of light. Satellites continually circulate our earth, capturing images and wavelengths reflected from every location on the globe. For any one location on earth, thousands of images can be combined to classify the site’s land cover. Advanced computing technology can be programmed to digest all of these images and split the earth into land cover type pixels, one of which is open water. Open water is defined as any area of surface water unobstructed by aquatic vegetation. Thus, changes in the spatial extent of open water locations over a long period of time can be discerned including new and lost waterbodies or seasonal changes. The temporal and spatial resolution of the satellite imagery dictates how accurate and precise the results are. To distinguish one water-related ecosystem type from another, further processing of this open water data is required in conjunction with other datasets.

Open water spatial extent data, using Landsat satellites at a 30 m resolution[1], has been generated for the entire globe from 2001-2015. From 2016 onwards (up to and including 2030), higher spatial and temporal resolution satellites, including both optical and radar satellites, will be used. For example, 20 m Sentinel 1 (radar) and 10 m Sentinel 2 (optical) satellites, used in combination with Landsat satellites, will allow for a more precise delineation of water bodies both in spatial terms (due to the higher spatial resolution) and in temporal terms (due to the higher revisit time). In addition, this mixed satellite approach which includes radar allows the mapping of surface waters in cloud permanent areas where optical sensors provide very few observations. The methodology to process and generate spatial extent data is consistent regardless of different satellite data sources.

The data sources used to generate the 2001-2015 dataset include individual full-resolution 185 km^2 global reference system II scenes (images) acquired by the Landsat 5, 7 and 8 satellites. These three satellites captured images which are distributed publicly by the United States Geological Survey (USGS). Together they acquire multispectral imagery at 30 meter resolution in six visible, near and shortwave infrared channels, plus thermal imagery at 60m (TM and ETM+) and 100 m (OLI)[2].

Nature of Data on Lakes, Rivers and Estuaries

Spatial Resolution

The 2001-2015 dataset includes freshwater and saltwater rivers, lakes and estuaries greater than 30 m^2. The vast majority of rivers are not captured as they are too narrow to detect or are blocked by forest canopy. To generate open water spatial extent

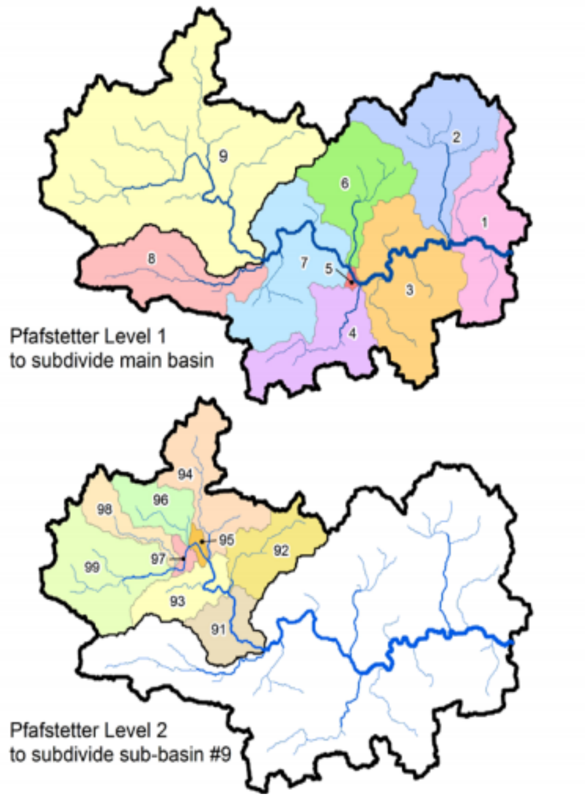

Figure 2 Sub-National Basins and Sub-Basins Approach Adopted by HydroBASINS dataset (adapted from Lehner, 2014)

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[1] This dataset was generated through a partnership with Google Earth Engine, the European Commission’s Joint Research Center, and the National Aeronautical Space Agency coordinated by UN Environment.

[2] The Thematic Mapper (TM), the Enhanced Thematic Mapper Plus (ETM+), and the Operational Land Manager (OLI) are instruments used on Landsat satellites to enhance their spatial, spectral, radiometric, and geometric performance.

data per country (and to exclude saltwater seas and oceans), the Food and Agriculture Organization (FAO)'s Global Administrative Unit Layers (GAUL) national boundaries dataset (FAO, 2015) is applied, which includes UN Member State-recognized boundaries. To generate data at a sub-national level, the WWF HydroBASINS (Lehner & Grill, 2013) dataset is applied. This dataset delineates each country into its primary watershed boundaries, which are based on elevation. These main basins are further divided into sub-basins by splitting main channels and tributaries (Figure 2). Where a HydroBasin crosses one or more national boundaries (transboundary basins), only the proportion of water within each national boundary is reported.

Temporal Resolution

The 2001-2015 dataset primarily includes surfaces that are under water for all months of a year, though accounts for seasonal and climactic fluctuations of water (meaning lakes and rivers which freeze for part of the year and seasonal waters are captured). Areas of permanent ice, such as glaciers and ice caps as well as snow covered land areas are not included. Areas of consistent cloud cover can inhibit the observation of water surfaces with traditional optical satellites and in these limited locations it is challenging to capture spatial extent data; radar satellite imagery will compliment observation in these areas.

Calculating National Percentage Change of Spatial Extent of Lakes, Rivers and Estuaries

To calculate percentage change of national spatial extent of lakes, rivers and estuaries using the 2001-2015 dataset, a baseline period needs to be defined against which to measure change. This methodology uses 2001-2005 as the 5-year baseline period. Averaging all earth observations annually and over a five year period accounts for seasonal and climactic fluctuations in water-related ecosystems. Using this baseline period, percentage change of spatial extent is calculated using the following formula:

$$Percentage\ Change\ in\ Spatial\ Extent = \frac{(\beta - \gamma)}{\beta} \times 100$$

Where β = the average national spatial extent from 2001-2005

Where γ = the average national spatial extent of any other subsequent 5 year period

The nature of this formula yields percentage change values as either positive or negative, which helps to indicate *how* spatial extent is changing. If the value is negative, it represents a gain in spatial extent while if the value is positive, it represents a loss in spatial extent. It is important to note that the use of 'positive' and 'negative' terminology is purely mathematical and does not necessarily imply a positive or negative state of the water-related ecosystem being monitored. The percentage change generated represents how national spatial extent of lakes, rivers, and estuaries is changing over time. However, percentage change of spatial extent at a national scale should be interpreted with caution because sub-national and waterbody changes in spatial extent are not captured. As the dataset will be shared with water managers, changes in the spatial extent of lakes, rivers, and estuaries should be examined at smaller waterbody scales too.

SPATIAL EXTENT OF ARTIFICIAL WATERBODIES

The methodology to generate spatial extent of artificial waterbodies from earth observations is largely the same as the methodology for lakes, rivers, and estuaries and will thus not be repeated. Artificial waterbodies, or waterbodies created by humans such as reservoirs, canals, mines and quarries, are also captured as 'open water' by earth observations. Open water is defined as any area of surface water unobstructed by aquatic vegetation.

Artificial waterbodies are differentiated from other open waters because they are not natural ecosystems, though they may still form artificial ecosystems of significant importance for countries.

From this open water dataset, artificial waterbodies are disaggregated from lakes, rivers, and estuaries through two processing steps. The first step uses the basic premise that open water locations where spatial extent has increased or decreased significantly from one year to another indicate an artificial waterbody has been formed. Open water spatial extent data across a country is generated annually, starting in 2001, and from this, the national spatial extent of both new and lost open water (based on the 'original' national spatial extent in 2001) can be determined. This is further refined by examining if the shift in spatial extent remains constant over a year, to distinguish from waterbodies changing in spatial extent due to seasonal fluctuations.

The second processing step utilizes the Global Reservoir and Dam (GRanD) (Lehner *et al.*, 2008) geospatial database which contains polygons for over 6,500 reservoirs globally. The reservoirs captured in the GRanD database are primarily from large dams and countries are encouraged to augment this by providing locations of smaller dams. The open water dataset where lakes, rivers, and estuaries have been removed is overlaid with the GRanD dataset to further refine a dataset which is only artificial waterbodies. Finally, the dataset of spatial extent of vegetated wetlands (see next section) is also excluded, to prevent duplication. The resulting global dataset of artificial waterbodies, further disaggregated into national datasets as well as basins and sub-basins (using HydroBASINS) will be shared with all countries.

Calculating National Percentage Change of Spatial Extent of Artificial Waterbodies

Similarly to the spatial extent of lakes, rivers, and estuaries dataset, this artificial waterbodies dataset will be available from 2001 onwards. This methodology uses 2001-2005 as the 5-year baseline period. Averaging all earth observations annually and over a five year period accounts for seasonal and climactic fluctuations in water-related ecosystems. Using this baseline period, percentage change of spatial extent is calculated using the following formula:

$$Percentage\ Change\ in\ Spatial\ Extent = \frac{(\beta - \gamma)}{\beta} \times 100$$

Where β = the average national spatial extent from 2001-2005

Where γ = the average national spatial extent of any other 5 year period

The nature of this formula yields percentage change values as either positive or negative, which helps to indicate *how* spatial extent is changing. If the value is negative, it represents a gain in spatial extent while if the value is positive, it represents a loss in spatial extent. It is important to note that the use of 'positive' and 'negative' terminology is purely mathematical and does not necessarily imply a positive or negative state of the water-related ecosystem being monitored. The percentage change generated represents how national spatial extent of artificial waterbodies is changing over time. In many regions globally, spatial extent of artificial waterbodies is generally increasing over time, a trend which is likely the result of the construction of new reservoirs for water storage, climate change, and flood irrigation (Pekel et al., 2016). This dataset can be used in conjunction with other spatial extent datasets to inform national water changes.

SPATIAL EXTENT OF VEGETATED WETLANDS

Vegetated wetlands are a particularly significant water-related ecosystem and enable numerous ecosystem services related to clean water and sanitation including water retention, filtration and provision. As such, the spatial extent of vegetated wetlands is generated separately from lakes, rivers, estuaries, and artificial waterbodies (see previous sections).

Generating Spatial Extent Data on Vegetated Wetlands from Satellite Imagery

The determination of the spatial extent of vegetated wetlands can be supported by satellite imagery following a similar approach to the spatial extent of lakes, rivers, estuaries, and artificial waterbodies. However, remote sensing of vegetated wetlands is more challenging than for these open water bodies, due to the large diversity of freshwater and brackish wetland ecosystems (e.g. swamps, fens, peatlands, marshes, paddies, and mangroves). This is particularly the case for the production of global datasets on the spatial extent of vegetated wetlands, which requires the development of fully automatic processes that are able to discriminate vegetated wetlands from other land cover types, for all wetland types and in all climatic and hydrological conditions.

For the purposes of Indicator 6.6.1, vegetated wetlands include a large variety of wetland types which all have their own vegetation, structural, and functional traits. These traits may vary in: permanently or temporarily inundated areas; natural and man-made wet areas such as paddies; but also wetlands which are never flooded and only temporarily wet. The production of a global spatial extent of vegetated wetlands from satellite observations must be able to cope with this large variety of vegetation types and hydrological conditions, and with its inherent temporal (seasonal and annual) dynamics. The use of multi-temporal (exploiting dense time series of satellite imagery) and multi-source (using both optical and microwave remote sensing) satellite-based image analysis helps to substantially increase the classification accuracy of vegetated wetlands.

The spatial extent of vegetated wetlands requires the spatial delineation of man-made and natural wetlands, over very large geographical areas (from national to global scales) and at a high spatial resolution (10 to 30 m) in order to detect small wetland habitats. The enhanced observation capacity offered by the Sentinel satellites of the European Copernicus program complement the Landsat satellites to provide both the large-scale coverage as well as the necessary temporal and spatial resolution to accurately derive information on the extent of vegetated wetlands. In particular, the global and systematic observation scenarios of these satellite missions and the development of multi-sensor solutions makes it possible to fully exploit the capacity offered by optical and radar satellites to improve wetland inventories globally.

The method to detect vegetated wetlands from satellite Earth Observations is based on an approach which detects the physical properties of wetland areas (e.g. soil moisture and vegetation water content) from multi-temporal SAR (Synthetic Aperture Radar) and optical satellite imagery, combined with other geospatial datasets related to the topography of the area, the hydrography of the watershed and its drainage network, and the soil types. Using different image enhancement methods, spectral and topographic wetness indices from optical observations can be combined to maximize the contrast between open water, vegetated wetlands and other land cover types. Some automatic thresholding can then be subsequently applied to delineate open water, wet, and dry areas for each month of the year. These monthly aggregates can then be combined to the soil moisture observations derived from SAR observations, exploiting the SAR sensitivity to water content. The aggregation of all monthly observations yields the water and wetness frequencies during the observation period (which typically covers a number of years to reduce the climate impact such as long droughts) and the determination of a Water/Wetness Probability Index (WWPI) which is the basis for the delineation of vegetated wetlands.

With the emergence of the Sentinel missions, their free and open data policies, and the commitment of the European Commission to provide long term continuity to the satellite observations, the high temporal dynamics of wetlands can be captured more accurately than before resulting in more reliable and representative mapping of vegetated wetlands.

The high revisit time of Sentinel-1 (every 12 days everywhere in the world) and Sentinel-2 (every 5 days on all land surfaces and coastal areas, to be complemented with US Landsat 8 imagery) allows for the production of high quality monthly aggregates that separate open water, wet, and dry areas. On the spatial level, the high spatial resolution of Sentinel-1 and Sentinel-2 (10 to 20 m) increases the detection accuracy especially in capturing the large variety of small wetland habitats and in detecting small vegetated waterbodies.

Classifying wetland areas into specific types of wetlands, such as peatlands or marshes, can be done with remote sensing approaches which use the same types of satellite imagery (Sentinel 2, Landsat 8 and Sentinel 1) and apply some supervised classification with machine learning algorithms. The classification of wetland areas into wetland types requires the use of reliable training datasets that typically are based on field ground-truthing (i.e. *in situ* data from field surveys) (GLOB Wetland, 2017).

The GEO-Wetlands initiative of the Group on Earth Observations (GEO) is developing a Global Wetland Observation System (GWOS). GEO is a voluntary intergovernmental partnership of 105 governments (including the European Commission) and around 120 participating organizations fostering open and collaborative production and use of EO data in support of global decision making. GEO-Wetlands is one of the many GEO initiatives and provides a framework for international cooperation in the development and knowledge-exchange of EO solutions for the inventory, assessment and monitoring of wetlands. One of its objectives is to develop a robust EO approach to global wetlands inventories (GEO-Wetlands, n.d.). The development of scientifically sound and statistically meaningful approaches for large scale mapping of vegetated wetlands is underway in Africa and Europe, through the GlobWetland Africa project of the European Space Agency and the Satellite-based Wetland Observation Service (SWOS) project of the European Commission. Discussions are taking place in GEO-Wetlands to converge and harmonise EO-based solutions for wetlands inventories and up-scale globally the approaches (expected to start in 2019).

There are already practical applications of earth observations for mapping global extent of vegetated wetlands and their changes over time for mangroves specifically (Rosenkvist, in preparation). Mangrove swamps are forested intertidal ecosystems that are distributed globally between approximately N32° to S39°. They occur under *Marine/Coastal Wetlands*: I (Intertidal forested wetlands) in the Ramsar Classification System for Wetland Types. Global maps of mangrove extent for the time period 1997-2000 have been generated by the US Geological Survey (Giri et al., 2011) derived from 30 m resolution Landsat data, and for the time period 1999-2003 by the International Tropical Timber Organization (ITTO) and the International Society for Mangrove Ecosystems (ISME) with the World Atlas of Mangroves (Spalding, 2010), based on a combination of optical satellite data and national statistics and processed at UNEP-WCMC and FAO. Both global datasets are available in the public domain and provide a comprehensive picture of the geographical distribution of the world's mangroves at the turn of the 2000 millennium.

Annual global mangrove extents are currently being produced within the framework of the Global Mangrove Watch (GMW) (Lucas et al. 2014). These GMW annual maps are based on global mosaics of 25 m resolution satellite data, publicly and openly available from the L-band SAR sensors on-board the radar satellites (JERS-1, ALOS and ALOS-2) of the Japanese Space Agency (JAXA), supplemented with optical satellite data (primarily Landsat). With the capacity of the microwave signals to penetrate clouds and haze, SAR data are essential in cloudprone coastal areas and in regions affected by persistent fires. L-band SAR with its long wavelengths has in addition the capacity to penetrate the forest canopy and has proven to be an important tool for mapping the extent of mangrove forests. This is complemented by the ability of multi-spectral optical satellite data (e.g. Landsat and Sentinel 2) to discriminate different vegetation types and therefore provide more accurate distinction of the landward border of the mangroves. The GMW is an international collaborative project established within the framework of JAXA's Kyoto & Carbon Initiative science programme, set up to provide geospatial information about mangrove extent and changes to Ramsar, national wetland practitioners, decision makers, and NGOs. GMW is also a pilot project of the Global Wetlands Observation System (GWOS). The GMW will produce annual maps of global mangrove extent for eight epochs, 1996, 2007, 2008, 2009, 2010, 2015, 2016 and 2017, with corresponding change maps. From 2018, maps are foreseen to be available on an annual basis. The GMW 2010 map of global mangrove extent is available on the Global Forest Watch of the World Resources Institute (WRI).

Spatial Resolution

The global extent of vegetated wetlands based on Sentinel 1 and Sentinel 2 is meant to be available at 20 m spatial resolution, while the Global Mangrove maps from the GMW, which are based on 25 m L-band SAR data and 30 m Landsat data, is available at 30 m spatial resolution.

To generate spatial extent data and statistics per country, the national boundaries of the FAO Global Administrative Unit Layers (GAUL) dataset (FAO, 2015), which correspond to UN Member State-recognized boundaries, needs to be applied. To generate data at a sub-national level, it is recommended to use the WWF HydroBASINS (Lehner & Grill, 2013) dataset which delineates each country into its primary watershed boundaries and sub-basins. For transboundary basins, it is recommended to report on the proportion of wetlands which are within each national boundary.

Temporal Resolution

The global extent of vegetated wetlands is planned to be based on the processing of dense time series of Sentinel 1 and Sentinel 2 data (complemented with Landsat 8 data) acquired over a number of consecutive years (at least 3 years, preferably 5 years) to reduce the impact of climatic fluctuations such as long droughts or extreme rainfall events. The Global Mangrove maps from the GMW are currently produced on an annual basis.

Areas of consistent cloud cover inhibit the observation of land surfaces from optical sensors such as Sentinel 2 and Landsat 8. Although the mapping of vegetated wetlands (including mangroves) is based on the combined use of optical and radar satellite systems, the inherent limitations of optical sensors in cloud persistent areas limit the ability of the EO solutions to accurately capture the spatial extent of vegetated wetlands. However, the availability of radar-alone solutions allows wetland delineation within acceptable uncertainties as done for the mapping of the extent of tropical mangroves.

Calculating National Percentage Change of Spatial Extent of Vegetated Wetlands

To calculate percentage change of national spatial extent of vegetated wetlands, a baseline period needs to be defined against which to measure change. This methodology uses 2001-2005 as a five-year baseline period. Averaging all earth observations annually and over a five year period accounts for seasonal and climactic fluctuations in vegetated wetlands. Using this baseline period, percentage change of spatial extent is calculated using the following formula:

$$Percentage\ Change\ in\ Spatial\ Extent = \frac{(\beta - \gamma)}{\beta} \times 100$$

Where β = the average national spatial extent from 2001-2005

Where γ = the average national spatial extent of any other 5 year period

The nature of this formula yields percentage change values as either positive or negative, which helps to indicate *how* spatial extent is changing. If the value is negative, it represents a gain in spatial extent while if the value is positive, it represents a loss in spatial extent. It is important to note that the use of ‘positive’ and ‘negative’ terminology is purely mathematical and does not necessarily imply a positive or negative state of the vegetated wetland being monitored.

The percentage change generated represents how national spatial extent is changing over time. However, percentage change of spatial extent at a national scale should be interpreted with caution because sub-national and wetland-level changes in spatial extent are not captured. Water managers are encouraged to use this change in national spatial extent dataset in combination with sub-national and waterbody-level data to interpret changes in spatial extent of vegetated wetlands.

SUB-INDICATOR 2

WATER QUALITY OF LAKES AND ARTIFICIAL WATER BODIES

This section includes the methodology for monitoring two parameters of water quality (chlorophyll *a* and total suspended solids) from earth observations on lakes. All geospatial data generated is subject to validation by national authorities, as it is recognized that existing national water quality data may exist for many lakes. Thus, all water quality data generated by earth observations for Sub-Indicator 2 will be shared with countries to facilitate the formulation of the most accurate depiction of how the water quality of their lakes may be changing over time. It is important to note that as advances in technology to capture data using earth observations occur this will lead to ongoing refinements and revisions of the methodology.

Generating Chlorophyll *a* and Total Suspended Solids Data on Lakes from Satellite Imagery

Satellite-based earth observations can capture certain types of water quality data. With the high-frequency revisit time of combined Landsat and Sentinel satellites paired with instruments like OLCI, MODIS, and VIIRS, it is possible to regularly monitor aquatic systems in nearshore coastal and inland waters, especially still non-turbid lakes. This approach can only provide information on concentrations of in-water materials that affect the colour of water. These materials include chlorophyll *a* (Chl), which is the primary pigment in phytoplankton (the primary source of food on the food-chain), and total suspended solids (TSS). The concentrations of Chl and TSS can be used as proxies to infer other important waterbody characteristics. High Chl can be an indicator of eutrophication, though specific nutrient and oxygen concentrations are not captured. High TSS in a water body may reflect degrading land and can often indicate higher concentrations of suspended materials which tend to clog water habitats and negatively affect ecosystems. Monitoring change in Chl and TSS using earth observations has been tested and developed globally, by initiatives and groups such as NASA, GEO AquaWatch (GEO, 2017), and the European Space Agency.

Nature of Data on Lakes and artificial water bodies

Spatial Resolution

The sensor instruments used to detect TSS and Chl determine the spatial resolution of water quality within lakes which can be detected. Some of the more accurate water quality sensors have 250-350 meter resolution, while less accurate sensors can detect TSS and Chl changes to 100 m resolution. The minimum lake size that can be monitored is also restricted due to the lower quality of images captured at lake edges; images of water pixels adjacent to land pixels tend to be less accurate at detecting water quality changes.

Temporal Resolution

The combined revisit frequency of satellites such as Landsat, Sentinel-2 and Sentinel-3 is approximately 3 days, assuming cloud-free conditions. When cloud-free images become available, the images are processed and reduced to water quality indicators. When the images are collected under hazy conditions, the accuracy of the water quality detection degrades. Therefore, image detection accuracy may vary from time to time according to environmental conditions.

Changes in Chl and TSS Concentration of Lakes and artificial water bodies

Chl and TSS results are derived using empirical algorithms, generated for each individual pixel to ensure the spatial variability within each lake is fully captured. Results are averaged over a year for each lake to produce lake-wide Chl and TSS concentrations and small localized fluctuations in concentration of these two parameters are not shown. On any one day, the pixels representing each concentration of Chl or TSS are quantified and a lake-wide average is determined for that day. Figure 3 demonstrates the capability to detect TSS from satellite imagery across a lake on a daily basis.

The change in concentration of both Chl and TSS can be determined from comparing an annual average against the baseline. This annual average Chl and TSS will be averaged every 5 years, which will be compared to the Chl and TSS baselines to generate a percentage change. The locations where percentage change is excessive can be targeted for increased water quality monitoring and management. Table 2 shows an example annual report generated for a country.

Table 2 Example Annual Chl and TSS Report for Hypothetical Country X

Water Quality Parameter	Date Range of "Present Day" Annual Average	Latitude	Longitude	Baseline Concentration	Present Day Average Concentration
Chl	01-01-2018 to 31-12-2018	XXX	XXX	XX mg/m3	XX mg/m3
TSS	01-01-2018 to 31-12-2018	XXX	XXX	XX mg/m3	XX mg/m3

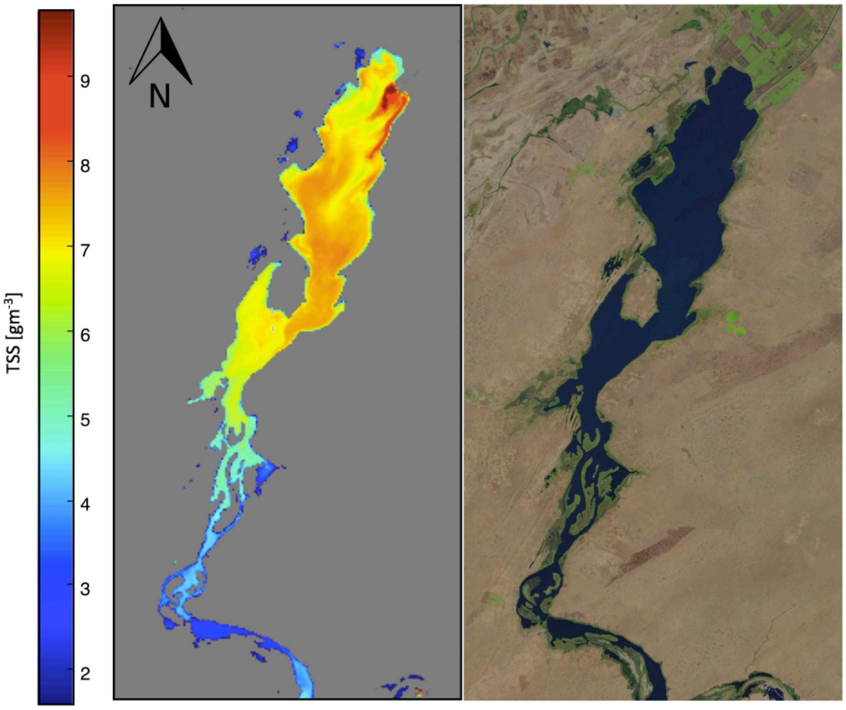

Figure 3 Landsat-derived concentration of Total Suspended Solids, TSS, (left) of Lake Guiers in Senegal. The warmer colors indicate more turbid waters. The highest TSS concentrations are associated with areas where water flows into the lake from the Senegal River. The true-color image (acquired Jan 21, 2014) is shown to the right.

LEVEL 2 DATA: METHODOLOGY FOR MONITORING AND REPORTING

The Sub-Indicators included in Level 2 are aspects of Indicator 6.6.1 which must be monitored 'in situ' or within countries themselves. Level 2 data collected by countries should be submitted to the custodian agency(s), who will submit appropriate data to UNSD. Level 2 data is divided into three Sub-Indicators: quantity of water in rivers and estuaries (Sub-Indicator 3); quality of water in lakes, rivers, estuaries, artificial waterbodies, and groundwater (Sub-Indicator 4); and quantity of groundwater within aquifers (Sub-Indicator 5).

SUB-INDICATOR 3

QUANTITY (DISCHARGE) OF WATER IN RIVERS AND ESTUARIES

River and estuary discharge, or the volume of water moving downstream per unit of time, is an essential metric for understanding water quantity within an ecosystem and availability for human use. This section describes key considerations for monitoring discharge and provides criteria for discharge data generated to support Indicator 6.6.1.

***In Situ* Monitoring Methods**

There are a variety of methods for monitoring discharge *in situ* and selection should be based on the size and type of the waterbody, terrain and velocity of water flow, the desired accuracy of measurement, as well as finances available (Dobriyal et al., 2017). Some of the most common and accessible approaches are described here.

Gauging Stations

In many countries, gauging stations are most prevalent means for measuring river discharge as they allow for continuous and often real-time monitoring. These are fixed locations along a river or estuary where the change in height of the water surface, or stage, is monitored. Data on the stage is captured continuously and this data is combined with periodic discharge measurements to generate a continuous record of discharge.

Discharge Meters and Instruments

Discharge meters and other instruments can be used to monitor discharge. For example, propeller, pygmy or electromagnetic current meters are often used to measure velocity and can be used in conjunction with cross-sectional area methods to obtain flow rates. Acoustic Doppler Current Profiler's (ADCPs) are widely used for larger rivers/estuaries to accurately measure bed depth, velocity, and discharge. They are attached to boats and dragged along a waterbody, sending out acoustic waves and measuring acoustic reflectance. Meters and instruments like ADCPs are significantly more costly than other methods of measurement, and require skilled operators. However, in larger rivers they may be the most appropriate option, especially when no gauging stations are present.

Citizen-Science Approaches for Small Rivers

For small rivers or for countries with low capacity to monitor discharge, citizen science approaches can be adopted to augment more traditional discharge monitoring data after quality control by national authorities.

Timed Volume (Bucket) Method

This method works best for small rivers on hilly terrain and requires finding a waterfall-like feature. A bucket of known volume is held at this waterfall and the time it takes to fill it is recorded. This time measurement should be repeated at minimum 5 times, and then averaged. To calculate the discharge, divide the volume of the bucket by the average time to fill it. This method requires a waterfall and cannot be completed by holding the bucket under the water surface. If a waterfall-like feature is not present, a weir, or small dam, can be established which channels all flow into one location for more accurate flow measurement. Establishment of a weir can be costly at first but is good for long-term monitoring because the discharge is calculated at the same location every time.

Cross-sectional (Float) Method

This method is best for small rivers on flatter terrain, though can be applicable for larger rivers if they are relatively straight with uniform flat terrain. An object is floated along a river stretch that is longer than the river width. A starting location is chosen and the depth along this entire width is measured in equal intervals. This provides the river cross-sectional area. Time measurements for the object to float downstream from one end to the other are taken, at minimum 5 times, and then averaged. To get the velocity of the river, divide the river stretch length by the average time for the object to float this length. This method is less accurate, as friction caused by the streambed contents is not accounted for; the velocity can be multiplied by a friction coefficient factor to capture surface/streambed flow differences. Once the velocity is obtained, it is multiplied by the total cross-sectional area at the starting point to determine the discharge.

Location of Monitoring

The chosen monitoring method may dictate where along a river or estuary the discharge is captured. For example, if fixed weirs are in place, monitoring will always take place here. Since *in situ* discharge monitoring can be time and cost-intensive, choosing strategic locations which represent a whole river or estuary is recommended. The minimum monitoring effort is to locate one flow measuring site within proximity to each basin's exit (into another basin). In addition, monitoring at the exit point from all major tributaries adds a substantial level of information. Where there is a local impact on discharge 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.

Frequency of Monitoring

The quantity of water in a river or estuary can change rapidly in response to rainfall and weather patterns. The more data on discharge there is, the higher the accuracy is of that discharge data. However, again it is important to focus efforts and choose a strategic frequency for monitoring. Data on discharge should ideally be collected at a given location once a month at minimum (ideally at a daily frequency) and this data can then be used to determine annual and long-term trends. The quantity of water in estuaries may be significantly influenced by tidal inflows, thus this indicator is limited to the freshwater inflows to the estuary from the upstream river.

Modelling Discharge

In addition to *in situ* monitoring, discharge may also be modelled from one of the many available models which use climate and land-use data, amongst other data, to estimate both natural and present day flows. In some countries these or similar models have already been developed for the local context and are calibrated using real measured data. It is recommended that modelled discharge data is complimented by measured *in situ* data wherever possible to ensure accuracy.

Criteria for Indicator 6.6.1 Data

Discharge data provided to the custodian agency(s) will be quality checked to ensure data integrity. The following criteria will be used and should be considered for all discharge data captured:

- Units should be in million meters cubed per annum (Mm^3/a).
- Discharge data from each river/estuary monitored should be collected *at least once per month*. This data should then be averaged to obtain an **annual average discharge** per river/estuary monitored.
- Each basin should have *at minimum one sampling location*, at the point where its water exits into another basin or crosses a national boundary. For the purposes of global monitoring, sub-basin discharges such as those from tributaries should be kept separately and can be used for local level management.

Every 5 years, countries should provide annual average discharges per basin for 5 years to the custodian agency(s). These five years of discharge data will be averaged to produce five year rolling means. This is in order to smooth short-term variability. Collection of discharge data generates statistics that describe the quantity of water in a river/estuary over time. In order to examine this change over time, percentage change in discharge will be generated and validated between the custodian agency(s) and the country. Calculating percentage change at a national level requires the establishment of a common reference period for all basins, which can either be based on historical discharge data (preferred) or modelled discharge data if available. In cases where these are unavailable, a more recent period can be adopted to represent the 'baseline' or reference period.

To calculate percentage change in discharge for each five year period following the reference period, the following formula is used:

$$Percentage\ Change\ in\ Discharge = \frac{(\beta - \gamma)}{\beta} \times 100$$

Where β = historical 5 year reference discharge

Where γ = the average discharge of 5 year period of interest

This percentage change in national discharge of rivers and estuaries will be reported to UNSD every 5 years.

SUB-INDICATOR 4

QUALITY OF WATER-RELATED ECOSYSTEMS

Sub-Indicator 2 within the Level 1 monitoring of Indicator 6.6.1 includes two parameters of water quality in lakes and artificial water bodies: chlorophyll *a* and total suspended solids. However, it is widely recognized that other parameters of water quality must be considered and must be measured *in situ*. Thus, the water quality data collected from earth observations in Level 1 will be augmented by the water quality data being collected within SDG Indicator 6.3.2, for which UN Environment is a custodian[3]. Indicator 6.3.2 measures the "proportion of bodies of water with good ambient water quality" and applies to most of the water-related ecosystem categories of Indicator 6.6.1 (with the exception of vegetated wetlands).

The procedure for monitoring of water quality is documented in the SDG Indicator 6.3.2 Methodology[4] and is not repeated here. It recommends five core water quality parameters to be monitored at minimum for surface

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[3] UN Environment also elicits the support of the Global Environment Monitoring System for freshwater (GEMS/Water) for Indicator 6.3.2 monitoring and reporting

[4] INCLUDE REFERENCE ONCE FINAL

waters: dissolved oxygen, pH, electrical conductivity, a measure of nitrogen and a measure of phosphorus; and three core water quality parameters at minimum for groundwater: pH, conductivity or salinity, and nitrate.

However the format of the water quality data needs to conform to the principle of this 6.6.1 indicator; i.e. it needs to represent a percentage change over time. Accordingly, the data collected for Indicator 6.3.2 needs to be converted. An assumption is made for Indicator 6.6.1 that if 100% of the water bodies are in “good” condition that would approximate a natural reference condition.

Countries will be reporting national and basin-level Indicator 6.3.2 data every 5 years to the UNSD. Thus, Sub-Indicator 4 water quality data will be reported at the same time for Indicator 6.6.1 automatically to the UNSD. Alignment between reporting of Sub-Indicator 2 and 4 data will be completed.

SUB-INDICATOR 5

QUANTITY OF GROUNDWATER WITHIN AQUIFERS

The quantity of groundwater within aquifers is important information for many countries that rely heavily on groundwater availability. The volume of groundwater stored in an aquifer is most traditionally estimated using a combination of parameters including the spatial extent of an aquifer, an aquifer’s saturated thickness, an aquifer’s storativity or storage ability, and the level of groundwater. However, for the purposes of Indicator 6.6.1 monitoring, the ‘head’ or level of groundwater within an aquifer can solely be measured as a proxy for groundwater volume within an aquifer.

Location of Monitoring

Measuring the level of groundwater within an aquifer is done through the use of boreholes. One of the challenges in setting up monitoring is choosing the location of boreholes which will adequately represent the total groundwater situation for an aquifer. 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. It is recommended that sufficient boreholes to characterise the area should 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 stabilise prior to any measurement.

Frequency of Monitoring

Groundwater levels 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). Seasonal and wet/dry cycle influences need to be understood and hence monthly monitoring is optimal, but collection at least twice per year, in the wet and dry seasons, is necessary.

Criteria for Indicator 6.6.1 Data

Groundwater quantity data provided to the custodian agency(s) will be quality checked to ensure data integrity. The following criteria will be used and should be considered for all groundwater level data captured:

- Units should be in meters (m).
- Point measurements of groundwater level within aquifers should be collected *at least twice per year*. This data should then be averaged to obtain an **annual average groundwater level** per aquifer monitored. Understanding the seasonal and other short term changes is a necessary aspect of management of groundwater but should only be considered as part of the local management of the groundwater.
- Each aquifer monitored should have *at minimum one borehole* that can be used for groundwater level measurements.

Every 5 years, countries should provide annual average groundwater levels per basin for 5 years to the custodian agency(s). These five years of groundwater level data will be averaged to produce five year rolling means. This is in order to smooth short-term variability. Collection of groundwater level data generates statistics that are a proxy to the quantity of groundwater in an aquifer over time. In order to examine this change over time, percentage change in groundwater level will be generated and validated between the custodian agency(s) and the country. Calculating percentage change at a national level requires the establishment of a common reference period for all basins, which can either be based on historical groundwater level data (preferred) or modelled data if available. In cases where these are unavailable, a more recent period can be adopted to represent the 'baseline' or reference period.

To calculate percentage change in quantity for each five year period following the reference period, the following formula is used:

$$Percentage\ Change\ in\ Quantity = \frac{(\beta - \gamma)}{\beta} \times 100$$

Where β = historical 5 year reference groundwater level

Where γ = the average groundwater level of 5 year period of interest

This percentage change in national quantity (level) of groundwater within aquifers will be reported to UNSD every 5 years.

REPORTING OF THE INDICATOR

This Indicator tracks changes over time in the extent of water-related ecosystems. To do so, a percentage change from a baseline provides countries with a measurement of how well their water-related ecosystems are being protected and restored over time. The methodology for defining and calculating the baseline differs for each Sub-Indicator and has been described within each Sub-Indicator section. Data for Sub-Indicator 1 and 2 is generated annually and is used to calculate percentage change every 5 years. A 5 year percentage change is used to smooth the inherent short-term variability of water-related ecosystems and the use of annual data to infer change is not recommended and should be used with discretion. Therefore, annual data will be made available to countries for validation, but will not be submitted to the United Nations Statistical Division (UNSD).

In addition to the national-level percentage change data reported to UNSD for global comparison, sub-national (basin and waterbody-level) data will also be generated and are particularly relevant for sub-national and local decision making on the protection and restoration of water-related ecosystems. Thus, while only some data is reported to UNSD, all geospatial data will be made available to countries should they be interested in comparing their own data or examining waterbodies in greater detail within a basin. This comparison is encouraged, as globally available data may not reflect national inventories or on the ground knowledge of water-related ecosystems completely accurately without validation.

Country Validation of Level 1 Global Data

As described above, all globally available data generated for Sub-Indicators 1 and 2 will be shared with countries for validation. This geospatial data will be generated annually at national, sub-national, and waterbody scales. While this data is generated annually, the measurement to report change in extent requires validation every five years. Validated annual datasets will be utilized by the custodian agency(s) to generate percentage changes on behalf of countries. In other words, countries will only be required to validate national-level data every five years. Validation of national data can take the following forms:

1) Accept: country verifies data provided and validates its use. Data reported to UNSD.
2) Reject: country denies the use of data provided, and does not provide any replacement data. No data reported to UNSD.
3) Modification: country modifies the data provided and re-submits it to be used for reporting to UNSD.
4) Provides own data: country denies the use of data provided, and instead provides their own geospatial data which is used for reporting to UNSD.

Table 3 shows the Sub-Indicators and their reporting cycles. It is imperative that the data generated for Level 1 is validated by national authorities to ensure accuracy of globally available data.

Table 3 Reporting of Indicator 6.6.1 Data

Sub-Indicator	Data Type	Spatial Scale	Units	Reporting Cycle to UNSD
Sub-Indicator 1 Spatial extent of water-related ecosystems	Percentage change in 5-year average of spatial extent of lakes, rivers and estuaries	National	% (and direction of change)	Every 5 years
	Percentage change in 5-year average of spatial extent of artificial waterbodies	National	% (and direction of change)	Every 5 years
	Percentage change in in 5-year average of spatial extent of vegetated wetlands	National	% (and direction of change)	Every 5 years

Sub-Indicator 2 Water quality of lakes	Percentage change in 5-year average of Chl concentration	National	% (and direction of change)	Every 5 years
	Percentage change in 5-year average of TSS concentration	National	% (and direction of change)	Every 5 years
Sub-Indicator 3 Discharge of rivers and estuaries	Percentage change in 5-year average of discharge	National	% (and direction of change)	Every 5 years
Sub-Indicator 4 Water quality of water-related ecosystems	Percentage change over 5-year average of water-related ecosystems in 'good' condition	National	% (and direction of change)	Every 5 years
Sub-Indicator 5 Quantity of groundwater within aquifers	Percentage change in 5-year average of groundwater level	National	% (and direction of change)	Every 5 years

Each percentage change will be accompanied with a direction of change. This information is crucial to know, as it indicates *how* the component is changing. The direction is recorded as either positive or negative but the use of this terminology does not necessarily imply a positive or negative state of the water-related ecosystem being monitored. For example, Country X may find a 3% gain in artificial waterbodies over the last 15 years. Its national water managers can use this information against known datasets such as agricultural water withdrawals, population growth, climate patterns, precipitation, etc. to infer why this gain occurred. In Country X's case, the 3% gain may be due to increased damming of rivers into storage reservoirs which have positively benefitted its hydroelectricity generation and flood mitigation; however, localized droughts, wetland loss, and negative ecosystem impacts over the 15 years were also widespread due to water diversions. The same Country X may find a 2% gain in lakes, rivers, and estuaries, but this could be due to a series of very wet years which caused severe flooding and ecosystem inundation. This example illustrates that a 'gain' of surface water extent can be both beneficial and detrimental to the ecosystem and also society, depending on the local and national context.

Water managers need to take stock of the percentage change and direction of change across the sub-indicators to obtain a better understanding of how and why different water-related ecosystems are changing. These changes should not be viewed in isolation but rather their potential interaction(s) and the hydrological scale at which these interactions are occurring should be considered for informed decision-making.

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