WP1 - Policy, Stakeholder and Service Analysis

D1.6 Report on links and gaps between satellite EO and water related SDGs and climate indicators

Project Identification	
Project Full Title	Water Scenarios for Copernicus Exploitation
Project Acronym	Water-ForCE
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Water-ForCE is a Coordination and Support Action (CSA) that has received funding from European Union's Horizon 2020-research and innovation programme under grant agreement number: 101004186.

Document Identification

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History of Changes

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15.10.2021	V0	First Concept and Outline (USTIR)
15.11.2021	v0.5	First full draft of the deliverable (USTIR)
05.01.2022	v0.6	Comments and inputs by IGB, GeoEcoMar and FvB

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08..02.2022	v0.7	Revised version by UTARTU, IHE, USTIR
14.02.2022	v0.8	Revised version by PML, USTIR
25.02.2022	v0.9	Revised version by dotSPACE, USTIR
03.03.2022	v1	Final version (USTIR)

List of Acronyms

CAMS	Copernicus Atmosphere Monitoring Service
CAR	Climate Assessment Report
CCI	Climate Change Initiative
CDOM	Coloured Dissolved Organic Matter
CDR	Climate Data Records
Chl-a	Chlorophyll-a
CMUG	Climate Modelling User Group

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CMS	Copernicus Maritime Surveillance, part of the Copernicus Security Service
ECV	Essential Climate Variable
EO	Earth Observation
EV	Essential Variable
GCI	Global Climate Indicator
GCRF	Global Challenges Research Fund
GEO	Group on Earth observation
GSWE	Global Surface Water Extent
IOCCG	International Ocean Colour Coordinating Group
K_d	diffuse attenuation coefficient
LST	Land Surface Temperature
MSI	Multispectral Instrument onboard Sentinel-2
OLCI	Ocean and Land Colour Instrument onboard Sentinel-3
PaWaQ	Pan-African Water Quality Programme
SDD	Secchi disk depth
SDGs	Sustainable Development Goals

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SLSTR	Sea and Land Surface Temperature Radiometer onboard Sentinel-3
SRAL	Synthetic Aperture Radar Altimeter onboard Sentinel-3
SST	Sea Surface Temperature
SWT	Surface Water Temperature
TROPOMI	TROPOspheric Monitoring Instrument
TSM	Total Suspended Matter
UN	United Nations
WFD	Water Framework Directive
WP	Work Package
WWQA	World Water Quality Alliance

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1. Introduction

1.1 Project & Work Package Introduction

The **Horizon 2020** project **Water-ForCE** (Water scenarios for Copernicus Exploitation) is developing a Roadmap to better integrate the entire water cycle within the **Copernicus services**, thereby addressing needs and requirements from the user community, the current disconnection between remote sensing / in-situ observations and upgrade of the modelling algorithms. The clarity in terms of the needs and expectations of both public and private sectors from the core Copernicus Program and the wider research and business innovation opportunities will be delivered. The Roadmap will then also advise on a strategy to ensure effective uptake of water-related services by end-users and further support the implementation of relevant directives and policies.

The Water-ForCE consortium is led by the University of Tartu (Estonia) and consists of 20 organizations from all over Europe. It will bring together experts on water quality and quantity, in policy, research, engineering, and service sectors. Through close collaborations with these communities, Water-ForCE will among others:

- **Analyze EU and international policies** to identify where the Copernicus services can improve monitoring programs and how the Copernicus data can be more effectively used in developing and delivering the next versions of EU legislations.
- **Specify the technical requirements** for future Copernicus missions in order to make them more suitable for inland and coastal water remote sensing (e.g. adding new spectral bands on Sentinel-2E and onward, improved spatial resolution, hyperspectral sensors).
- **Optimize future exploitation** of Copernicus Services for inland water monitoring, management, legislation implementation, service provision and research &

development through enlarged service portfolio and optimized delivery of water related products and services.

The project is divided into eight work packages (WP), each of them focusing on a specific problem and/or target of the Copernicus service (see Figure 1). The project started 1 January 2021 with a duration of three years.

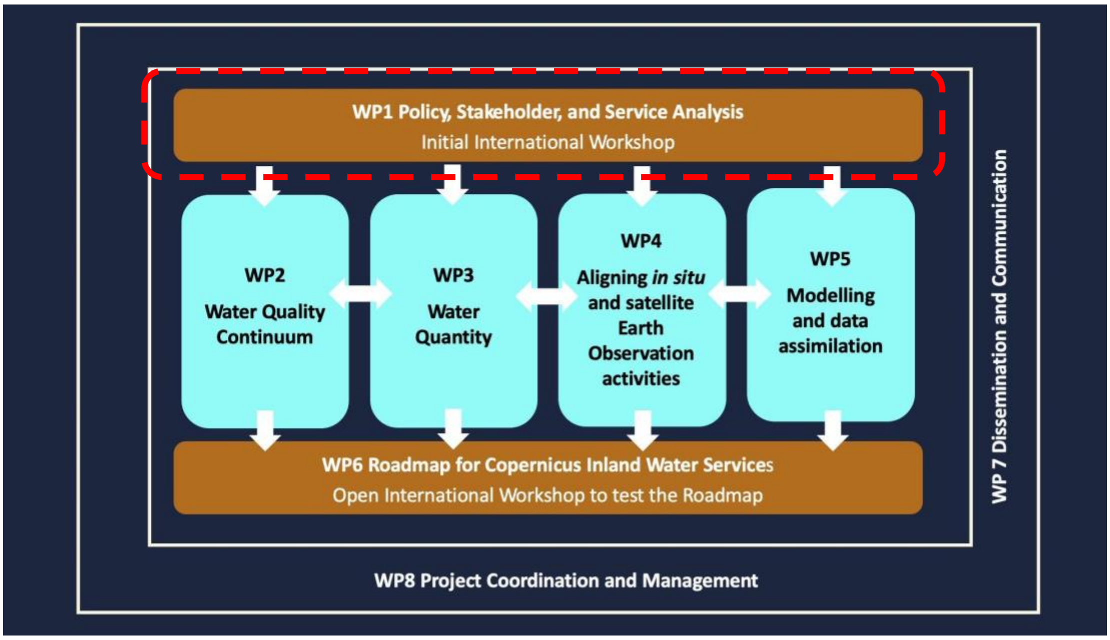

Figure 1 : Organizational structure of the different work packages in the Water-ForCE project.

1.2 WP1 overall aim and expected impact

The overall aim of WP1 is to identify key users within the different public domains and business sectors and evaluate whether operational services can meet policy goals. The

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expected impact is increased coverage of EU policies clearly identifying which and how the project would like to address them.

WP1 has six tasks and two milestones, as shown in the table below. The tasks and milestones are closely linked and together provide input to WPs 2-6.

Table 1 : Overview of WP1 tasks and deliverables

Task	Deliverable
T1.1 Value chain and stakeholder identification	D1.1 List of stakeholders (M7)
T1.2 Public domain and business sector identification	D1.2 Report with assessment of domain-specific and sectoral policies and legislation (M10)
T1.3 Links between mission-service-application	D1.3 Report with analysis of links within Copernicus programme and between Copernicus programme and domain / sector policies (M14)
T1.4 End-user needs and requirements identification	D1.4 Report with end-user needs and requirements (M14)
T1.5 Innovation need and opportunities	D1.5 Report with analysis of business

	opportunities, validated by industry (M14)
T1.6 Contribution towards societal challenges, missions and SDGs	**D1.6 Report on links and gaps between satellite EO and water related SDGs and climate indicators (M14)**
MS1	WP1 Participants workshop Stakeholder input on the evolution of the Copernicus Water Services (M4)
MS2	Input to the Roadmap (WP6)

This report is the deliverable for Task 1.6.

1.3 Objectives and approach of Task 1.6

The Task 1.6 "Contribution towards societal challenges, missions and SDGs" coupled to this deliverable is aiming to identify the links and gaps between satellite EO variables and water-related SDGs. Under this task, we aim to identify and synthesise existing research and engage with stakeholders with global reach and international programmes to build understanding about human health, sanitation and food security EO needs in relation to water quality and quantity. This task also aims to summarise the requirements of users of climate information.

We carried out extensive literature/online research to identify the EO capabilities for inland waters and links/gaps between EO and SDGs and links with Global Climate Indicators (GCIs). We provide a summary of existing Copernicus Services based on the service websites and presentations from service representatives given during the Water-

ForCE workshop "Copernicus water component evolution – policy expert" (20-21 October 2021). We have identified and engaged with key related projects and international organisations/initiatives to better understand requirements, needs and opportunities with regards to climate research and SDGs. This information was collected though:

- Water-ForCE workshops and other activities (e.g. webinars) where key international organisations and representatives of global initiatives were invited.
- Active engagement (memberships, stream works etc.) with international initiatives and relevant projects (e.g. ESA Climate Change Initiative (CCI)).

Note, this document does not address links between EO for water resources and EU policy and legislation, as this is included in Task 1.3 (D1.3 Report with analysis of links within the Copernicus programme and between the Copernicus programme and domain/sector policies). Here, we focus on a link-gap analysis from the **global** perspective.

The outcomes from this task feed directly into WP6, the roadmap for Copernicus Inland Water Services.

1.4 EO capabilities for inland waters

This report does not deal with the technical disciplines of optical, radar, thermal and microwave remote sensing but provides a short summary of the EO capabilities for inland waters that are relevant to SDGs and climate research as well as some key references. The technical disciplines of remote sensing for inland waters are detailed in WP2-WP5.

EO provides a vast opportunity for monitoring inland water resource quantity and quality. In terms of water quality, optical medium- and high-spectral resolution satellite instruments can retrieve optically active in water constituents, as indicators of water quality. Furthermore, optical remote sensing can also be used retrieve **bathymetry and habitat maps** in shallow waters. Water pollution events, e.g. **oil slicks**, can be detected using active microwave sensors like Synthetic Aperture Radar (SAR) combined with optical sensors for algae discrimination and thermal instruments. These variables can be derived indirectly from satellite variables, including **salinity**, **trophic status**, **phytoplankton size classes**, **primary productivity, algal toxins, nutrients, dissolved oxygen, pollutants/metals/microbial contaminants**.

A recent review of these variables is included in Chawla et al. (2020) and the IOCCG report No. 17 (IOCCG, 2018). An overview of the use of EO for water quality monitoring specifically in support of the Water Framework Directive (WFD) is also provided in a white paper from the H2020 EOMORES and CoastObs projects (Papathanasopoulou et al., 2019).

Water quantity can also be retrieved using optical or synthetic aperture radar (SAR) sensors on satellite platforms. Radar altimeters can measure the height of the water surface from the satellite, or **water level.** River **discharge** can also be estimated indirectly from satellite parameters, using variables that can characterise hydrodynamics of flow, such as areas of the water-surface, channel slope, average channel width, and velocity of flow in open channels. **Surface water area** and/or **flood extent** can be detected using indices from optical sensors or active or passive microwave sensors. Soil moisture, which is a variable used for catchment hydrology, can be retrieved from active or passive microwave remote sensing (e.g. SMOS, SMAP), synergies between different satellite systems enable us to monitor soil moisture at an unprecedented regularity and scale. Soil moisture is also being monitored through the ESA Copernicus (https://www.copernicus.eu/en/news/news/observer-monitoring-soil-moisture-space-copernicus) and NASA (https://smap.jpl.nasa.gov/) programmes.

Thermal imaging provides data of water and land temperature with a number of applications such as in circulation patterns in lakes, heat dispersion in thermal effluent plumes, aquaculture and fisheries management, monitoring of droughts and food security.

A recent summary of approaches for water quantity can be found in Chawla et al. (2020).

2. Existing Copernicus Services

This section outlines water relevant products for SDG reporting and climate research offered by the existing Copernicus Services for Atmosphere, Marine, Land, Climate Change, Security and Emergency Management and highlights some gaps/opportunities. In addition, Water-Force deliverable 2.2 (Review document, gap analysis and recommendations on Copernicus products related to water quality) and deliverable 3.2 (Review document and recommendations on Copernicus products related to the hydrological water balance) will review existing products and services and make recommendations on Copernicus products for inland waters in the future as well.

This analysis is based on the Copernicus Services catalogues and presentations from service representatives given during the Water-ForCE “Copernicus water component evolution – policy expert” workshop (20-21 October 2021):

- Copernicus Climate Change Service, ECMWF
- Copernicus Emergency Service, Joint Research Centre, European Commission
- Copernicus Land Monitoring Service, European Environment Agency
- Copernicus Land Monitoring Service, Joint Research Centre, European Commission
- Copernicus Marine Service, Mercator Ocean International
- Copernicus Security Service, European Maritime Safety Agency

Copernicus Services provide a vast resource of operational satellite products covering the topics of atmosphere, marine, land, climate change, security and emergency (Figure 2). Each service has a differing degree of maturity; however, the vast majority of data are made freely available and accessible around the world.

The existing Copernicus Services cover relevant EO variables for water monitoring and management, however there are gaps where there remain opportunities for a Water thematic Hub. These opportunities will be described in detail as part of WP6, a roadmap for Copernicus Inland Water Services, although a brief overview of the existing Copernicus services is shown here, describing the relevant operational inland water variables.

Popp et al (2020) analysed the interdependencies of satellite based CDRs within the ESA CCI programme and identified the needs for consistency. For lakes the retrieval dependencies that were identified were Aerosol, Clouds, Ozone, Water vapour, Fire, Land cover, Soil Moisture, Glaciers, HR LST, Permafrost, Snow, Ocean Colour, Sea Level. Direct process dependencies included: Aerosol (deposition, energy); Water vapour (water cycle); Fire (deposition); Ice Sheets (water cycle, transport), Land cover (transport, ecosystem interaction); Soil moisture (Water Cycle); Glaciers (energy cycle, melting/thawing/freezing, HR land cover (transport); LST (energy cycle, water cycle, radiation interaction); permafrost (Water cycle, Energy cycle, emission/evaporation); Snow (Water Cycle); Sea level, and SST. These are offered by different Copernicus Services.

Figure 2: Diagram of existing Copernicus services and infrastructure (from https://www.copernicus.eu/en/accessing-data-where-and-how/conventional-data-access-hubs).

2.1 Copernicus for SDGs

In 2018, Copernicus outlined how their existing services can help achieve the UN SDGs. In particular, they show how the existing Copernicus Land Monitoring Service (CLMS) can address SDG 6 (Clean Water and Sanitation; Figure 4). The existing CLMS provides "near-real time information on global inland water bodies and their seasonal replenishment, lake and river water levels, temperature, turbidity and trophic state, including potential water availability from snow and ice cover" (Copernicus, 2018).

This report provides links for EO data with the SDGs, which aligns with the aims of Water-ForCE. However, this can be expanded upon in a future Water thematic Hub, which can address more SDGs (See Section 3) and provide new indicators for achieving the SDGs.

Figure 3: Diagram of existing Copernicus and links to SDGs (Copernicus, 2018)

2.2 Atmosphere

The Copernicus Atmosphere Monitoring Service (CAMS) provides data on air pollution and health, solar energy, greenhouse gases and climate forcing (https://atmosphere.copernicus.eu/).

There are several relevant products from the Atmosphere Service that are linked with processes in inland and coastal waters. This includes some of the retrieval and direct

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dependencies mentioned above (e.g. aerosols). Opportunities to combine greenhouse gas concentrations from the CAMS service with surface water extent and water colour (e.g. Chl-a) from EO data in order to derive estimates of GHG emissions from inland waters (e.g. CO_2, CH_4 and NO_x, NH_3) are highlighted in the literature (Deemer et al., 2016; DelSontro et al., 2018). For example, DelSontro et al. (2018) estimated the greenhouse gas emission (CO_2, CH_4, N_2O) from global lakes and impoundments using lake water extent and Chl-a concentration (as a proxy of productivity) from EO data.

2.3 Marine

The Copernicus Marine service provides data and services towards marine policy implementation, support of Blue growth and scientific innovation (https://marine.copernicus.eu/).

Current coastal zone products that are part of this service include:

- turbidity, sea surface temperature, wind, ocean colour, sea ice, waves.
- buoys, tide gauges, HFR, biogeochemical data
- 3D models with tides, waves, biogeochemistry, currents,

The service consists of satellite, in situ and modelled data. In the future, the service will strengthen the interface between Copernicus marine and land services, improve monitoring/forecasting of hydrology and river discharges, evolution of the land cover /land use monitoring, long-term projections for the coastal ocean, and harmonised data access. Additionally, new satellite products are anticipated for this service (e.g. time evolving bathymetry, turbidity, waves, wind, marine debris), as well as coastal models operated by Member States, standardised modelled river discharges (freshwater, nutrients, particulate and dissolved matter), and integration of coastal model derived information.

The intention is to harmonise these into a Copernicus Coastal Thematic Hub, jointly with the marine, land, emergency and climate change Copernicus services.

2.4 Land

The Copernicus Land Monitoring Service (CLMS) provides data on land cover and change, land use, vegetation state, water cycle and the Earth's surface energy for environmental terrestrial applications (https://land.copernicus.eu/). The water-related products include at medium to high resolution:

- lake water quality and
- water bodies,

at coarse to medium resolution, the following products:

- soil water index,
- water bodies,
- lake surface water temperature,
- lake water quality,
- lake ice extent,
- snow cover extent,
- snow water equivalent,

and the following non-gridded product,

- water level.

The water bodies product uses global surface water extent (GSWE) from Landsat 7/8 and Sentinel-1/Sentinel-2. Future updates will include GSWE algorithm adaptation for Sentinel-2, quality control and documentation.

The lake surface water temperature product currently covers 1,000 to >2,000 lakes, with future coverage of >4,000 lakes expected with Sentinel-3 C.

The current water quality products included in the service are: lake surface reflectance, turbidity and trophic state. These cover 4,264 large lakes using Sentinel-3 Ocean and Land Colour Instrument (OLCI) data (300 m spatial resolution) and 2,000 lakes with Sentinel-2 data (100m spatial resolution). Monthly mean and multi-annual monthly means are also provided for baseline and reference monitoring for SDG6.3.2 by UNEP. Chlorophyll-a, cyanobacteria and product uncertainties are expected to be introduced to the service in 2022.

The lake and river water level product covers rivers >300m wide and lakes > 500 km2 (156 lakes) using Jason-3 and Sentinel-3 Synthetic Aperture Radar Altimeter (SRAL). Future plans will expand the number of stations for rivers and add Sentinel-6 data.

In addition to these inland water variables there are water-related variables as part of the Land Service, including:

- snow water equivalent
- snow cover extent
- lake ice extent
- soil water index
- surface soil moisture

2.5 Climate Change

The Copernicus Climate Change service (https://climate.copernicus.eu/) offers data on the past, present and future climate, in addition to tools for climate change mitigation and adaptation. Specifically for the water sector, this service is aimed at the fields of water allocation, flood management, ecological status and industrial water use. The water-related variables for climate include:

- temperature,
- precipitation,
- water magnitude,
- water quality,
- air conditions,
- temperature,
- precipitation,
- river flow, and
- unregulated river flow.

Additionally, the Copernicus Climate Change service provides hydrological seasonal forecasts, aimed at anticipating water stress, droughts and floods.

2.6 Security

The Copernicus Security service provides near-real time EO data to support Europe's security challenges, targeting crisis prevention, preparedness and response in three key areas: maritime surveillance, border surveillance, and support to EU External Action for detection of security threats. The maritime surveillance service is managed by the European Maritime Safety Agency (http://www.emsa.europa.eu/copernicus.html). Data for all three parts of the Security service are available for authorised users only.

The Copernicus Maritime Surveillance (CMS) service products that are water-related include:

- Vessel detection and vessel traffic
- Feature detection (e.g. aquaculture)
- Activity detection
- Oil spill detection
- wind and wave
- pollution monitoring

2.7 Emergency Management

The Copernicus Emergency Management Service provides data for selected emergency situations from natural or man-made disasters (https://emergency.copernicus.eu/).

The relevant water products for this service include:

- flood extent and impact maps,
- historical flood delineation,
- tsunami risk assessment,
- hydrological in situ data (river discharge and water level),
- meteorological in situ data (precipitation, temperature, solar radiation, vapor pressure, wind speed etc.).
- probabilistic flood forecasts
- flash flood indicators

- flash flood now-casting and notifications
- flood alert exceedances
- soil moisture, snow maps and anomalies
- hydrological seasonal outlook
- impact forecasts
- Sentinel- SAR observed flood event, water extent, reference water mask, exclusion mask, uncertainty values, affected population, and affected landcover,
- standardised precipitation index
- low flow indicator (LISFLOOD modelled)
- soil moisture anomaly (LISFLOOD modelled)
- GRACE total water storage anomaly

The relevant components of the Emergency service include the European and Global Flood Awareness System (EFAS & GloFAS) and the European and Global Drought Observatories (EDO & GDO), consisting of in situ, modelled and satellite datasets (Sentinel-1 and GRACE).

3. Links between EO & SDGs

This section describes the links found between EO variables and SDGs in terms of the relevant targets and indicators for each SDG. We have considered all SDGs in the sub-sections below and identified direct and indirect links with EO water-related variables. A direct link exists when EO can be used to calculate or directly contribute to relevant SDG targets. For example, surface water area and bathymetry from satellite sensors can be used to monitor changes of water quantity in reservoirs and support Target 6.4. Indirect links refer here to describe the relationships when EO data cannot solely calculate or directly contribute to relevant SDG targets. For example, access to water is considered one of the major hurdles to keeping girls in education and keeping women developing careers (SDG4) and EO products of water sufficiency can help by supporting the development of solutions, but access to water does not appear as a principal factor in SDG4. A series of examples are provided. Note that these examples are not exclusive and they mainly focus on monitoring, early warning and water resource management.

The 17 SDGs (https://sdgs.un.org/goals) are part of the United Nations (UN) 2030 Agenda for Sustainable Development, which recognises the need for a global partnership in order to tackle poverty, improve health and education, reduce inequality, spur economic growth, tackle climate change and preserve our land, oceans and water resources. These goals provide a shared "blueprint" for all people to ensure peace and prosperity across the globe, now and into the future.

The provision of clean, sustainable water and sanitation (SDG 6) is fundamental to reduce poverty and end hunger (SDG1&2) and to sustain economic development (SDG8,9,11&12) and health and wellbeing (SDG3) (MEA, 2005; Volker & Kisterman, 2011).

Table 2 summarises the linkages with each SDG. It includes EO variables that can be directly measured by satellite sensors i.e. they have a measurable effect on the signal measured by the remote sensor as well as variables that are not directly measurable from space but can be approximated with proxy relationships.

Table 2: Potential links between Sustainable Development Goals (SDGs) and Earth Observation (EO) variables water resources

SUSTAINABLE DEVELOPMENT GOALS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
EO water quality variables directly measurable from space																	
phytoplankton pigments			■			■	■	■				■	■	■	■		
algal biomass			■			■	■	■				■	■	■	■		
algal bloom presence, frequency, intensity			■			■	■	■				■	■	■	■		
submerged, emerging or floating aquatic vegetation						■	■	■				■		■	■		
total suspended			■			■	■	■				■		■	■		

SUSTAINABLE DEVELOPMENT GOALS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
matter			🟦			🟦	🟦	🟦				🟦		🟦	🟦		
turbidity			🟦			🟦	🟦	🟦				🟦		🟦	🟦		
Secchi disk depth			🟦			🟦	🟦	🟦				🟦		🟦	🟦		
attenuation coefficient, optical properties			🟦			🟦	🟦	🟦				🟦		🟦	🟦		
coloured dissolved organic matter			🟦			🟦	🟦	🟦				🟦		🟦	🟦		
Surface water temperature						🟦	🟦	🟦				🟦	🟦	🟦	🟦		
bottom substrate and bathymetry (shallow waters)						🟦	🟦	🟦				🟦		🟦	🟦		
EO water quality variables not directly measurable from space																	
salinity			🟦			🟦	🟦	🟦				🟦		🟦	🟦		

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SUSTAINABLE DEVELOPMENT GOALS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
trophic status			■			■	■	■				■	■	■	■		
phytoplankton size classes						■		■				■		■	■		
primary productivity			■			■	■	■				■	■	■	■		
algal toxins			■			■	■	■				■	■	■	■		
nutrients			■			■		■				■	■	■	■		
dissolved oxygen			■			■		■				■	■	■	■		
Pollutants/ microplastics/ metals/ microbial contaminants			■			■		■				■		■	■		
EO water quantity variables directly measurable from space																	

SUSTAINABLE DEVELOPMENT GOALS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
water level	🟦	🟦			🟦	🟦	🟦	🟦	🟦			🟦	🟦		🟦		
surface water area, flood extent	🟦	🟦				🟦	🟦	🟦	🟦		🟦	🟦	🟦		🟦		
EO water quantity variables not directly measurable from space																	
river discharge		🟦	🟦			🟦	🟦					🟦		🟦			

3.1 SDG 1: No poverty

Target 1.5

By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters.

This target is linked to EO inland water variables with regard to flood extent monitoring using SAR data (e.g. Sentinel-1). For example, reducing the exposure of those in vulnerable situations to climate-related extreme events can be undertaken with a near-real time monitoring and/or forecasting service for flooding. An early warning system could reduce the exposure of poor and vulnerable populations to the impacts of extreme events like flooding. Flood predictions are already part of the Copernicus Climate and Emergency Management Services, which could be featured in a future water thematic Hub. Soil moisture data can also provide early warning to flood and drought and collectively with data on flood extend and droughts can be used to support climate resilience strategies etc

3.2 SDG 2: Zero Hunger

Target 2.3

By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.

This target is linked to the use of EO for monitoring and accounting water resources for agricultural productivity. Particularly for remote regions, EO can provide monitoring of surface water extent and water quantity to aid establishing equitable access to water resources, particularly where they are scarce or span borders.

Target 2.4

By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.

EO products for flood extent and drought monitoring (surface water area) can support capacity building for communities to better predict and cope with extreme weather, drought and flooding. An early warning system for drought or flooding can help ensure a more resilient agriculture sector.

3.3 SDG 3: Good health & wellbeing

Target 3.9

By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.

Specifically, EO products for water quality are relevant for Indicator 3.9.2, which uses the rate of mortality attributed to unsafe water, unsafe sanitation and lack of hygiene (exposure to unsafe Water, Sanitation and Hygiene for All (WASH) services). EO products can monitor potentially harmful algal blooms (e.g. cyanobacteria), which pose a risk to water resources due to the presence of toxins. These can be retrieved directly through pigment presence (e.g. phycocyanin) or using bloom indices. Additionally, EO can monitor pollutants/metals/microbial contamination indirectly; for example, the presence of these may be inferred through their association with particulate and/or dissolved organic matter in plumes or resuspension events (IOCCG, 2018).

Target 3.d

Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks.

EO can provide an early warning system for water quality, whether for high suspended sediment or presence of potentially harmful algal blooms. Additionally, near-real time monitoring of water quality can allow for better management of water resources and reduce the risks of unnecessary exposure.

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3.4 SDG 4: Quality education

No directly relevant targets to EO water quantity or quality variables. Access to water is considered one of the major hurdles to keeping girls in education and keeping women developing careers. Relates to SDG4 too.

3.5 SDG 5: Gender equality

No directly relevant targets to EO water quantity or quality variables.

3.6 SDG 6: Clean water & sanitation

Target 6.1

By 2030, achieve universal and equitable access to safe and affordable drinking water for all.

Specifically, Indicator 6.1.1 is the proportion of the population using safely managed drinking water services. EO can assist in assessing the number of drinking water reservoirs that meet or exceed water quality criteria. Additionally, commercial satellites (https://www.planet.com/) now offer extremely high spatial resolution (3-5 m) images that can be used to observe smaller inland water bodies.

Target 6.3

By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

Indicator 6.3.1 is the proportion of domestic and industrial wastewater flows safely treated, and Indicator 6.3.2 is the proportion of bodies of water with good ambient water quality. EO can be used to assess river water quality downstream compared to upstream of wastewater flows (e.g. total suspended solids). Additionally, satellites can assess a suite of water quality variables (e.g. Chl-a, TSM, CDOM, SWT) and aquatic vegetation to identify the proportion of water bodies with good ambient quality on a global scale. Particularly, EO variables can be implemented in management strategies to assist with assessment of water quality in remote locations, where there may be little to no monitoring routine. This also ensures a consistent approach globally to assess water quality.

Target 6.4

By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.

To assess this target, Indicator 6.4.1 uses the change in water-use efficiency over time, and Indicator 6.4.2 is the level of water stress (freshwater withdrawal as a proportion of available freshwater resources). Surface water area can be retrieved from satellites using synthetic aperture radar (SAR). These data can be used along with bathymetry to estimate water quantity (i.e. available freshwater resources), and observe changes in water quantity over time in reservoirs (i.e. water-use efficiency).

Target 6.5

By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate.

For this target, Indicator 6.5.1 is the degree of integrated water resources management implementation (0-100), and Indicator 6.5.2 measures the proportion of transboundary basin area with an operational arrangement for water cooperation. EO can assist with broad spatial scale mapping of water resources, using optical or SAR data. Particularly, EO data is beneficial for transboundary maps of water resources, for accurate measurement of basin areas within operational cooperative agreements.

Target 6.6

By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.

Indicator 6.6.1 for this target measures the change in the extent of water-related ecosystems over time. This is ideally suited for EO approaches, where satellite time series maps of surface water extent with optical and/or SAR data can measure temporal change in water bodies. In particular, EO can acquire data for remote ecosystems (e.g. high-altitude lakes, tarns). An existing service for this indicator can be found here (Freshwater Ecosystem Explorer): https://www.sdg661.app/. This free service was funded by the UN Environment Programme, the European Commission and Google. It uses an archive of Landsat data (2001-2015), and Sentinel-1 and -2 data for recent years (2016 - present) for assessing spatial extent of water bodies. In the future it will include water quantity (volume) dynamics of lakes and reservoirs as well as river flow discharge. This existing service is well placed to be part of global component of the Copernicus Land Monitoring Service (CLMS, https://www.copernicus.eu/sites/default/files/2018-10/Copernicus_SDG_Report_July2018pdf.pdf) for assessing SDG 6 progress.

Target 6.b

Support and strengthen the participation of local communities in improving water and sanitation management.

EO can address this target through the provision of a free resource to monitor water quality and quantity. This service could support a broader participation of local communities towards management of their water bodies, and help generate established policies for local administration by using a transparent methodology.

3.7 SDG 7: Affordable & clean energy

Target 7.2

By 2030, increase substantially the share of renewable energy in the global energy mix

Target 7.3

By 2030, double the global rate of improvement in energy efficiency

EO can be used to identify suitable sites for new renewable energy, as well as ensure more efficient energy production. For example, clouds and aerosols can impact the amount of solar radiation reaching the Earth's surface, therefore solar energy facilities can benefit from these data to assess suitability for new sites. Floating photovoltaic installations could also benefit with EO data on wind, cloud and aerosols. Hydroelectric power sites could also use EO data for monitoring river discharge, water surface area and volume, sediment concentrations/ turbidity and temperature to identify suitable sites.

Equally, the environmental impacts of energy production can also be monitored with EO data. For example, potential negative impacts of power plant discharge (e.g. water temperature increases, algal bloom presence/ frequency) can be observed with EO data products.

3.8 SDG 8: Decent work & economic growth

Target 8.9

By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products

Clean and sustainable water resources can provide economic growth in a region (e.g. tourism, recreation, employment opportunities). Water quality and quantity variables derived from EO can help monitor and protect these valuable resources for the local economy.

3.9 SDG 9: Industry, Innovation & Infrastructure

Target 9.1

Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all

EO data can help to measure Indicator 9.1.2 (Passenger and freight volumes, by mode of transport). For example, the share of inland waterways toward total freight transport can be monitored using ship identification from SAR data (e.g. Sentinel-1).

Additionally, climate change is regarded as a threat to inland waterway navigation, with shrinking rivers and low flows (Nilson, 2019). However, the Copernicus Climate Change Service's Sectorial Information System (SIS) for Water can provide access to EO data on observed and future river flow, stream velocities and water levels.

3.10 SDG 10: Reduced Inequalities

No directly relevant targets to EO water quantity or quality variables. However, there are some links with SDG 6.1, since access to clean water could reduce inequalities.

3.11 SDG 11: Sustainable cities & communities

Target 11.5

By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations

EO can provide data on water-related disasters, such as flood extent monitoring. Currently, the Copernicus Emergency Management Service (CEMS) provides flood monitoring, including now-cast and probabilistic flood forecasts (Section 2.5). Flood extent can be monitored using SAR satellite data (e.g. Sentinel-1).

3.12 SDG 12: Responsible consumption & production

Target 12.2

By 2030, achieve the sustainable management and efficient use of natural resources

This target for SDG 12 could be measured using EO data for water quantity (e.g. for drinking water in reservoirs. Satellite radar altimetry can estimate water storage in large reservoirs. Additionally, optical EO data can help guide sustainable aquaculture for inland and coastal waters. For example, phytoplankton size classes and the ratio of Chl-a/TSM can provide information on the food quality and available food sources for bivalve aquaculture.

Target 12.4

By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment.

EO can monitor discharges to rivers, lakes/reservoirs or coastal waters using turbidity or TSM as a proxy for pollution (e.g. using Sentinel-2 or -3). Near-real time monitoring of discharges would minimize time for potential damage to the environment and animal or human exposure.

Target 12.a

Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production

Copernicus thematic service elements for water quantity would be a cost-effective approach for developing countries to manage their water use and anticipate future water needs. Additionally, EO could provide an early-warning system to users for threats to water resources (e.g. harmful algal blooms).

3.13 SDG 13: Climate Action

Target 13.3

Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.

EO data can monitor several indicators for climate change over inland waters, such as:

- Surface water extent (i.e. drought or flooding)
- Surface water temperature

- Water level
- Lake ice cover
- Algal bloom presence/intensity/timing
- Turbidity (erosion, sediment transport)

An open access EO service dedicated to these climate indicators could help raise awareness and build capacity for communities to react quickly to climate change impacts with a near-real time or early warning system (modelled from EO data). However, as in many of the cases described here sufficient investment into capacity building is nessecary.

Target 13.b

*Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States, including focusing on women, youth and local and marginalized communities * Acknowledging that the United Nations Framework Convention on Climate Change is the primary international, intergovernmental forum for negotiating the global response to climate change.*

EO can raise capacity for effective climate change-related planning and management in less developed countries, especially for high priority areas (e.g. freshwater resources and wetlands).

3.14 SDG 14: Life below water

Target 14.1

By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution

With regard to an inland water, EO data can monitor marine pollution via river and estuary discharge monitoring. Particulate matter can be inferred using turbidity and TSM concentrations derived from optical EO data (e.g. Sentinel-2 or-3), and plastics have been detected using optical EO data (e.g. Sentinel-2; Biermann et al., 2020). Inland water quality and the presence of eutrophication upstream in the catchment also has an impact on downstream coastal water quality. Chl-a concentrations upstream can be derived from EO (e.g. Sentinel-2 and -3), as well as bloom indices and cyanobacteria blooms (using the pigment phycocyanin as a proxy for Sentinel-3).

3.15 SDG 15: Life on land

Target 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.

In particular, EO can provide data for Indicator 15.1.2, the proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type. Freshwater resources can be mapped using satellite data, in order to establish the proportion of sites covered by protected areas. Furthermore, EO data can be used in order to monitor water quantity as well as quality in these important sites for biodiversity to ensure sustainable conditions.

Target 15.3

By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world

EO data for flood and surface water extent can be used to monitor the presence of desertification, drought and floods over time.

Target 15.5

Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species

Over 34,000 species of plants and animals are on the IUCN red list of threatened species (https://www.iucnredlist.org/) and live in wetlands (inland) habitats. Optical satellite sensors can provide data to monitor these wetland habitats, including water quality (TSM, trophic state, Chl-a, SWT) as well as macrophyte presence. This can ensure these habitats can sustain threatened species to protect and prevent extinction.

Target 15.8

By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species

EO data can be used for mapping invasive aquatic plants. For example, species-specific detection indices for the water hyacinth can monitor the presence and extent of this non-native species in freshwaters using drone-based hyperspectral sensors (Bolch et al., 2021). While not implemented with satellite data yet, this holds promise for newly launched and forthcoming hyperspectral satellite sensors to aid in monitoring aquatic non-native plants. A lot of focus is currently on water hyacinth. This can be detected by active and passive sensors (e.g. Simpson et al 2021).

3.16 SDG 16: Peace, justice & strong institutions

No directly relevant targets to EO water quantity or quality variables. However, EO can be used for water resource management in transboundary water use conflicts and support solutions.

3.17 SDG 17: Partnerships for the goals

No directly relevant targets to EO water quantity or quality variables. However, in principle, EO provides the spatial coverage to enable these partnerships and capacity building for monitoring global Inland waters.

Water-ForCE is a Coordination and Support Action (CSA) that has received funding from European Union's Horizon 2020-research and innovation programme under grant agreement number: 101004186.

4 Links with Global Climate Indicators (GCIs)

In this Section, we describe the connections between existing EO capabilities for water resources and the GCIs for Temperature and Energy, Atmospheric composition, Ocean and water and Cryosphere. The GCIs are a list of 7 essential climate variables (ECVs) that can be used to describe climate change, as established by the World Meteorological Organization (WMO). These include Surface Temperature, Ocean Heat, Atmospheric CO_2, Ocean Acidification, Sea Level, Glaciers, and Arctic and Antarctic Sea Ice Extent (Figure 3).

These GCIs belong to a larger group of 54 Essential Climate Variables (ECVs), which are the physical, chemical or biological variables, or group of linked variables, that characterize Earth' s climate. A complete list of these can be found on the Global Climate Observing System (GCOS) website: https://gcos.wmo.int/en/essential-climate-variables.

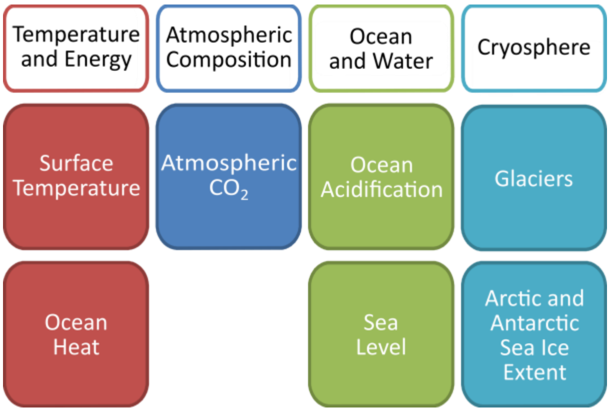

Figure 4 : The seven Global Climate Indicators identified by the Global Climate Observing System (GCOS) and endorsed by UN's WMO (from https://gcos.wmo.int/en/global-climate-indicators).

4.1 Temperature & Energy

Surface water temperature (SWT) regulates many physical, chemical, and biological processes in lakes and reservoirs, including reaction and metabolic rates, thermal stratification, species distribution, nutrient cycling, and the concentration of dissolved gases (Horne and Goldman, 1994). Furthermore, lakes are considered sentinels of climate change, or indicators of the effects of climate change on lakes and the catchment, due to their sensitivity to change (Adrian et al., 2009). Global lake summer SWT were found to increase rapidly in recent years (O'Reilly et al., 2015), and regional thermal shifts in lakes have been identified under a changing climate (Maberly et al., 2020).

SWT can be retrieved from satellite-based sensors using the thermal infrared bands (e.g. Landsat, MODIS, AVHRR), and this EO product can be used as a climate indicator for Temperature and Energy. In addition, EO could be an efficient tool to monitor the water level and water extent, and then provide information of water volume, which could support the use of hydropower as an important source of green energy.

4.2 Atmospheric composition

Surface waters are considered globally significant emitters of CO_2, CH_4, and N_2O to the atmosphere, with effects of aquatic GHG emissions on the atmosphere estimated to be almost 20% that of fossil fuel emissions (DelSontro et al., 2018).

Satellites can provide retrieval of atmospheric concentrations of GHGs (e.g. methane, carbon dioxide, ammonia and nitrogen dioxide) Sentinel-5 TROPOspheric Monitoring Instrument (TROPOMI) data. There is low reflectivity in the SWIR over water bodies, however there is some evidence for retrieval of GHG concentrations when cloud is present (e.g. CO; Martínez-Alonso et al., 2020). Alternatively, optical satellite data can be used to estimate water surface area and primary productivity or Chl-a, which can be used with in situ measured GHG concentrations to estimate emissions (DelSontro et al., 2018). These data can be used as a global climate indicator by better characterising the contribution of inland waters to GHG emissions estimates.

4.3 Ocean & water

The GCIs for Ocean and water are Ocean Acidification and Sea Level. However, inland water variables can also be indicators for global climate change. For example, surface water extent of inland water bodies can be an indicator for flood and drought conditions. Under a changing climate, there is a predicted increase in the probability and frequency of extreme events, including floods and droughts (IPCC, 2021). There is also high confidence that human-caused climate change has driven detectable changes in the global water cycle since the mid-20th century (IPCC, 2021).

Earth observation can provide information on the presence and extent of drought, through optical and SAR remote sensing of surface water extent and water levels.

Additionally, Lake colour (e.g. Chl-a) is an ECV, which can be derived from optical satellite sensors (e.g. Sentinel-2 or -3). Thermal remote sensing can detect changes in surface water temperatures, which are widely used as a proxy for climate change.

Although not specifically identified as an ECV or GCI, algal bloom timing (phenology) can be derived from EO data for inland waters (e.g. Palmer et al., 2015). Evidence of bloom thresholds or peaks occurring earlier can be an indicator of climate change.

4.4 Cryosphere

The cryosphere (ice sheets and glaciers) represents about 68.5% of the global freshwater on Earth (Stephens et al., 2020). Thus, it is a critical indicator of climate change to monitor changes in the amount of water held in the cryosphere. Satellites can monitor glaciers using optical (e.g. Sentinel-2) or SAR (e.g. Sentinel-1) data (Raup et al., 2015).

Also, EO can detect the time of freezing and thawing of ice, and determine the seasonality and phenology of lake ice cover, which is an ECV because lake ice extent (LIE) is sensitive to short- and long-term changes in temperature. River ice is also an important factor, especially for floods so some of this approach can be transeferable to river systems. Lake ice thickness (LIT) is another variable which could be a climate proxy and highly linked with temperature. The timing of lake ice (phenology) could be used to study climate change as well. Monitoring lake ice using EO can generally from three kinds of data: optical remote sensing, active microwave remote sensing, and passive microwave remote sensing (Murfitt & Duguay, 2021). For example, Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR) has been used for classification of LIE in northern hemisphere lakes (Heinilä et al., 2021).

5 Interactions & links with other relevant initiatives (initial requirements and needs)

In this Section, we are listing and describing initiatives with global outreach that have some focus on EO or translating EO into water monitoring/management. As part of the Water-ForCE project, we are engaging with several related projects and other international organisations/initiatives to better characterise and understand users-of-climate information and users for SDGs reporting. Water-Force is engaging with the global initiatives like World Water Quality Alliance (WWQA), GEMS/Water and GEO-Aquawatch. Water-Force is now a workstream of WWQA (supported by UNEP and Joint Research Centre-JRC). The relevant groups and projects are described below, including links with the aims of the Water-ForCE project and a future Copernicus inland water service.

5.1 GEMS/Water

The Global Environment Monitoring System for freshwater (GEMS/Water) was established in 1978 and is a system for global data for assessment of status and trends in global inland water quality. These data are shared through the GEMStat database (https://gemstat.org). These data cover in situ chemical, physical and biological variables for a range of rivers, lakes, wetlands, reservoirs and groundwaters in over 80 participating countries (Figure 5).

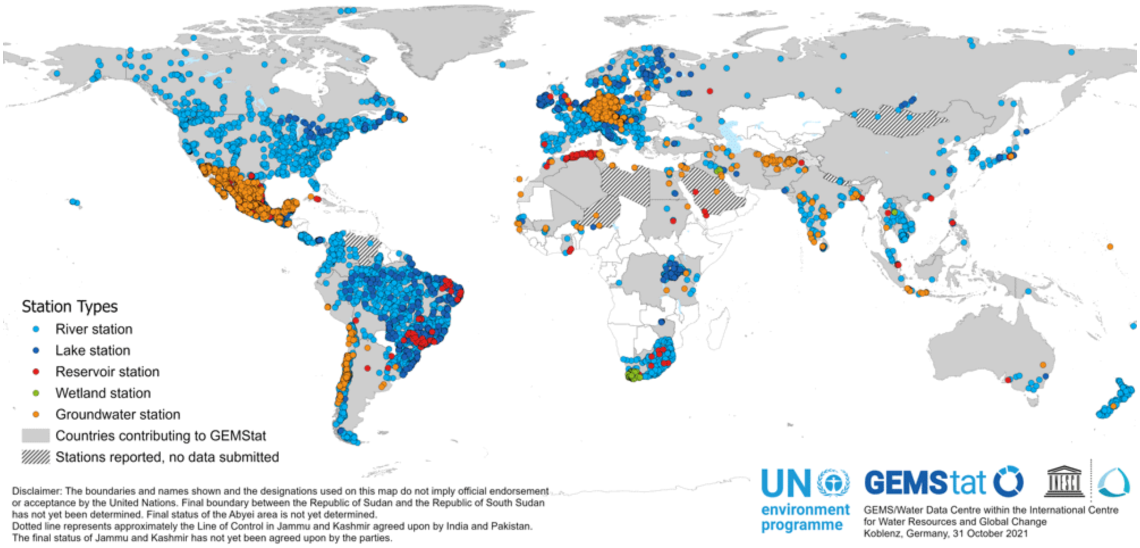

Figure 5 : Geographic coverage for water quality data in the GEMStat database (taken from https://gemstat.org/about/data-availability/)

These data can be linked to a future Copernicus inland water service, supporting water quality EO data calibration and validation efforts to improve algorithm accuracy. Also, GEMS/Water already supports SDG 6 (Indicator 6.3.2 proportion of water bodies with good ambient water quality), including methodology support, data management, quality assurance, indicator calculation and capacity development. UN Agenda 2030 is explicit in its recommendation that countries should develop local methods and targets that are appropriate for the context of each country, which serve as their contribution to sustainable development and to the monitoring.

During the Water-ForCE Workshop "Copernicus water component evolution – policy expert" in October 2021 the need for:

- Provision of in situ water monitoring data for cal val of remote sensing products
    - Definition of reference sites, targeted data collection
    - Clarification of data usage

- Improving existing Copernicus service products relevant for freshwater monitoring
    - Higher spatial and temporal resolution for temperature, Chl a, Turbidity products to allow for monitoring of riverine systems
    - Provision of waterbody & basin level aggregates/statistics
- Integrating freshwater and other service's products
    - Water quantity
    - Water quality
    - Hydromorphological & basin characteristics

To support global freshwater observing systems was highlighted by UNEP GEMS/Water Data Centre.

5.2 UN Group on Earth observation (GEO)

GEO is an intergovernmental partnership that aims to improve the availability, access and use of open Earth Observations to impact policy and decision making in a range of sectors (https://earthobservations.org/). GEO works towards achieving the SDGs by integrating EO data into the methodology of measuring indicators.

The GEO water quality initiative (AQUAWATCH) has a strong link to WaterForCE, as it aims to develop the global capacity and utility of EO derived water quality data, products and information to support effective monitoring, management and decision making. Other inland water-related initiatives include GEO-WETLANDS (global wetland observation), GEOGloWS (GEO Global Water Sustainability), and GDIS (Global Drought Information

System). These GEO initiatives are key existing platforms which link scientists and information with the users of climate information, in particular for the inland waters and EO communities. We are also actively involved with GEO Integrated Global Water Cycle Observation IGWCO) Community of Practice.

As part of the GEO community, UN Environment in collaboration with NASA, ESA, JRC are also working towards the integration of EO data with the SDGs. Specifically for SDG 6 indicators, UN Environment created a user guide/ methodology for using EO data to monitor changes over time in water quantity, spatial extent and water quality (https://eo4sdg.org/earthobservations-for-sdg6monitoring/). As part of this effort, the Freshwater ecosystem explorer was developed (https://www.sdg661.app/), and NASA carried out a pilot study for this initiative using 7 countries (Cambodia, Jamaica, Peru, Philippines, Senegal, Uganda and Zambia) and EO data for water quality, and water body and mangrove spatial extent. This is now an accepted Tier 1 methodology for use as an indicator for SDG 6 (Argyro Kavvada, NASA - GEO symposium presentation, May 2019 https://www.earthobservations.org/documents/me_2019_wps/S08_01_eo4sdg_Kavvada.pdf).

5.3 WWQA

The World Water Quality Alliance (WWQA) is a network of global multi-stakeholders that advocate the central role of freshwater quality in achieving prosperity and sustainability (https://communities.unep.org/display/WWQA). The WWQA was formed in 2019 as a direct response to UN resolution 3/10, which aims to address water pollution to protect and restore water-related ecosystems. As part of this, the resolution calls for better data collection, water monitoring, capacity-building and the development of a World Water Quality Assessment.

As part of the first core deliverable (Global assessment of water quality), WWQA aims to synthesize data from in-situ monitoring, water quality modelling and EO (triangulation approach) (Figure 7). Where EO could provide water quality products (e.g. Chl-a, turbidity) as well as water quantity products (e.g. water level, water extent) to support the assessment. Similarly, this is an important step in developing a Copernicus inland water service as part of Water-ForCE, and a key area where we can collaborate with WWQA.

Figure 6: WWQA core deliverables (from Water-ForCEworkshop presentation by Olivier Bouc, 20 Oct. 2021).

We presented Water-ForCE project and WWQA workstream to the 3rd Annual Global meeting in January 2022. We had the opportunity to engage with other workstreams such as Scenario Analysis for World Water Quality Assessment, Africa Use Cases, Capacity Development Consortium (CDCm), Citizen Science – Helping communities to track water quality in Sierra Leone for SDG 6.3.2 reporting, GlobeWQ STI Platform development, Towards a Pan-African Water Quality Programme (PaWaQ). The African Use Case presented an in-situ data, modelling EO approach is selected cases (Volta River Basin, Lake Victoria Basin, Cape Town Major Aquifer systems). These were also presented by WWQA at our Water-ForCE workshop in October. The challenges raised by this workstream were focused around in-situ data availability, data sharing, and fragmentation of institutional landscapes and governance structures in neighbouring countries when dealing with transboundary water bodies. However, some opportunities for developing a rehabilitation plan of Lotus river (a major pollution source in Cape Town) was recognised. PaWaQ workstream is working towards a framework for the Pan-African Water Quality Programme. As part of this, they carried out an African-wide survey to assess water quality monitoring and pollution in African countries. Their initial results (31 countries and 76 responses) included, among other, the need for '*'New technological advancement such as EO show great potential for adoption in a rapidly digitilising environment*", '*'Lack of basic capacity for water quality monitoring and management among some African countries hinders innovation. As such real innovations need to be based on available capacity*" and '*'Biological monitoring is a high priority intervention for inclusion into national water quality monitoring*".

5.4 ESA Climate Change Initiative (ESA-CCI) Lakes

The lake ECV dataset comprises the thematic variables Lake Water Level (LWL), Lake Water Extend (LWE), Lake Surface Water Temperature (LSWT), Lake Ice Cover (LIC) and Lake Water Leaving Reflectance (LWLR). ESA OC-CCI includes some of the larger lakes. In its Climate Assessment Report (CAR), ESA CCI Lakes summarises the added value of CCI products to Climate Research Group (CRG) and highlights some user feedback for climate science (https://climate.esa.int/media/documents/CCI-LAKES-0044-CAR_v2.1.pdf). CAR provides a summary of target user requirements based on GCOS (2016), a questionnaire survey and literature review. This contains requirements for measurement uncertainty, stability, spatial resolution, temporal resolution, length of record, maximum delay before availability of data, slicing of data, spatial aggression, data format, access, availability of uncertainty and projection. The ESA CCI user surveys and a Climate Modelling User Group

(CMUG) report (CMUG, 2020) highlighted the need for high frequency data without gaps and resources for post-processing. In the "Parameterisation of Lakes in Numerical Weather prediction and climate workshop" held in 2019, some of the capabilities of EO for monitoring lakes at a global scale were presented to mainly users of climate data. A requirement for global extinction coefficient data was brought to the EO scientists.

5.5 Inter-Sectoral Impact Model Intercomparison Project

Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) is aiming to better understand climate impacts across different sectors using a multi-impact model framework. Water-Force has engaged with ISIMIP2b through WP3 and WP6.

5.6 WATER4All

The WATER4All is an initiative co-funded between Agence Nationale de la Recherche (ANR) and European Commission (Horizon Europe) which aims to enable long-term water security for all through systemic changes in water-research innovation and fostering collaborations (http://www.waterjpi.eu/implementation/water-challenges-in-horizon-europe/candidate-partnership-water4all-2013-water-security-for-the-planet). This partnership initiative takes a cross-sectoral approach, considering policy, environment, economy, technology and society (Figure 6).

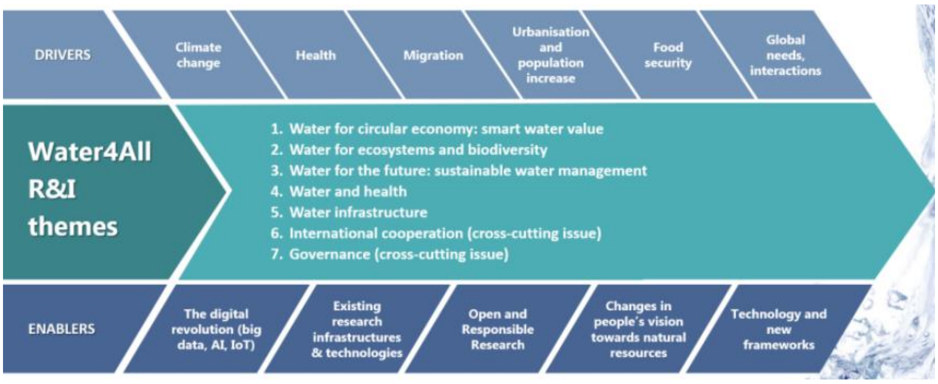

Figure 7: Water4All Research and Innovation themes, drivers and enablers (from Water-ForCEworkshop presentation by Olivier Bouc, 20 Oct. 2021).

In terms of water challenges for EO, this initiative links with the objectives of Water-ForCE. Research gaps identified by Water4All include the migration of pollutants in soils and water, modelling of flows and floods, water scarcity and drought, integration of different scales and sources for water quality assessment, large scale real-time observation networks for water availability and quality in the sub-surface, strengthening of observation data use by end users and decision makers, integration of freshwater into Digital Twin Earth and Digital Twin Oceans, and groundwater-surface-atmosphere interactions to assess impacts of global change. EO data can address some of these challenges for inland water (e.g. water surface area change for drought, integration of scales and sources for water quality assessment) and provide key input data for others (e.g. modelling flows and floods, Digital Twin Earth, etc.).

5.7 WQeMS

WQeMS is an H2020 funded project that aims to provide an open surface water quality emergency monitoring service for the water utilities industry (https://wqems.eu/). This project will use existing Copernicus products and services (e.g. Sentinel-2 and -3). Offered service products will include water quality features/changes, bloom event detection, land-water transition zone change detection, extreme event detection (floods/ oil spills), alert module (reporting and crowdsourcing), along with online training modules and development of an integrated system.

This aligns with Water-ForCEobjectives, although WQeMS focuses on a narrower set of inland waters for drinking water purposes.

5.8 GeoEssential ERA-PLANET

GeoEssential ERA-PLANET is an H2020 project which aims to create a knowledge base infrastructure to facilitate and advance information from the European Network of Earth Observation Networks (http://www.eneon.net/graph) and from other significant EO initiatives (http://www.geoessential.eu/). Using this infrastructure, they aim to generate new knowledge through Essential Variables (EVs) and support data integration and harmonisation.

In particular, WP7 of GeoEssential is strongly linked with the Water-ForCEaims. As part of this WP, partners created a GeoEssentials Indicators Toolbox and Dashboard, including maps, graphs, and SDG indicators derived from existing EO tools and platforms. This project also includes a showcase on SFG 6.4.2 (levels of water stress), where a workflow quantifies water stress level across Europe using Spinning Enhanced Visible and Infrared Imager (SEVIRI) sensor onboard the Meteosat Second Generation (MSG) satellites.

5.9 H2020 transforming water, weather, and climate information through in situ observations for geo-services in Africa (TAHMO)

TAHMO provides information on weather, water, and climate for sub-Saharan African by satellite and in-situ data. They presented some of their developments in a Water-ForCE workshop led by WP4. They communicated the need for accurate soil moisture data from satellite sensors.

5.10 Knowledge Centre on Earth Observation

The Knowledge Centre on Earth Observation is a service of the European Commission which aims to enable the uptake of EO data for EU policies and regulation (https://knowledge4policy.ec.europa.eu/earthobservation_en). In particular, the user uptake case "Earth Observation for SDGs" is of relevance to Water-ForCEgoals. They identified key EO datasets that are useful for monitoring SDGs. As part of this user uptake case, the Knowledge Center on EO synthesized the recent report by ESA, *Compendium of Earth Observation contributions to the SDG Targets and Indicators* (ESA, 2020). The overall contribution of EO data products to each indicator was assessed using criteria on readiness, adequacy and relevance, and the example synthesis for SDG6 is shown in Figure 8.

Water-ForCE is a Coordination and Support Action (CSA) that has received funding from European Union's Horizon 2020-research and innovation programme under grant agreement number: 101004186.

Figure 8: User uptake case "Earth Observation for SDGS" assessment of EO for SDG 6 (taken from https://knowledge4policy.ec.europa.eu/earth-observation/user-uptake-case-earth-observation-sdgs_en).

This assessment ultimately identified the key benefits of EO for SDG monitoring, including time series for change analysis, capacity for stable observations and cost-effectiveness to monitor remote areas. This sets the stage well for Water-ForCE to develop a roadmap to a Copernicus inland water service that can be used in support of achieving the SDGs.

5.11 Global Challenges Research Fund (GCRF)

GCRF is a fund to address the UN SDGs and is part of the UK official development assistance. There is a number of initiatives funded by GCRF that deal with water related SDGs. In 2017, University of Stirling hosted a workshop called "Water for all" focusing on user needs for SDG reporting and sustainable development. Representatives from Nicaragua (UNAN Leon), Ghana (CSIR-WRI), Tanzania (TAFIRI), Brazil (INPE), Kazakhstan

(KSRIWE) and India (IISC, Atree) attended the two-workshop to define regional priorities and co-design solutions based on technological developments such as EO. Their priorities were grouped around SDGs to Water quality and Sanitation, Water quantity and Transboundary Supply, Water and Food Diversity and Water & Human Health. The list of priorities included:

- Hydropower / agriculture conflicts in transboundary supply between Kazakstan, Tajikistan and Kyrgystan in Syrdarya river basin and Aral Sea
- Reduce water-borne diseases including cholera in Bangalore-Kamataka, India
- Identify and manage climate and anthropogenic impacts on fish landing in Lakes Tanganyika, Lalawi, Nyasa, Victoria and river Songwe
- Groundwater exploitation and development of an early warning system for floods and drought in Lake Volta
- Implementation of agri-culture farms for nutrient recycling in Lake Nicaragua Basin
- Improve sanitation, strategies to increase water quality in remote urban and rural communities in lower Amazon

The need for capacity building to bring EO capability to many of these regions to develop an enhanced capability at the national level to deliver on the SDGs reporting requirements was flagged by many of the participants.

In the GCRF-funded project "Developing statistical downscaling to improve water quality understanding and management in the Ramganga sub-basin" (https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/T003669/1) the need for higher spatial resolution satellite data (they currently use Planet Labs satellite sensors) was identified to monitor water quality in Ramganga sub-basin.

Another example comes from a GCRF-funded project between the University of Stirling and Environment and Population Research Centre (EPRC) in Bangladesh. The need for regionally tuned and validated EO products was highlighted in this project.

6 Conclusion & Recommendations

Here, we have identified links between 12 of the UN Sustainable Development Goals and EO variables for inland water quality and quantity. This highlights the relevance of EO capabilities towards achieving the SDG targets by 2030 and demonstrates the need for broad spatial scale and fine temporal resolution global monitoring of inland waters to achieve the SDGs. The links with all four GCI categories with EO variables are also established, demonstrating key ECVs that are relevant for inland waters. Clearly, EO can be a valuable tool for monitoring ECVs on a global scale for inland waters, including surface water temperature (Temperature & Energy); surface water extent and primary productivity for GHG emission estimates (Atmospheric composition); surface water extent, water levels, lake colour, surface water temperature, and algal bloom phenology (Ocean & water); and glaciers and lake ice extent (Cryosphere). We also show connections between Water-ForCE and several other international organisations and projects, and some of these were included in the Water-ForCE workshop held in October 2021. It is vital to continue these collaborations throughout the duration of the Water-ForCE project, to devise the most relevant and useful roadmap for a Copernicus inland water service (WP6).

Copernicus Services offer wide-ranging opportunities in support of the SDGs and GCOS especially in data poor countries. Water-related EO products are principally showcased in SDG6 and the UN Environment Programme have accepted the global surface water explorer as default data source for SDG 6.6.1. A future Water focused thematic Hub can address more SDGs and deliver new indicators for achieving them. Table 2 summarises the EO water-related variables that can be exploited in support of SDGs and GCOS.

Table 3: Summary of the EO water-related variables that can be exploited in support of SDGs and GCOS

	Category	EO variable
SDGs	SDG1: No poverty	Flood extent, soil moisture
	SDG2: Zero hunger	Water extent, water quality, flood extent, drought, soil moisture
	SDG3: Good health and wellbeing	Algal blooms, water quality
	SDG4: Quality education	Opportunities for exploitation of water related EO-products can be explored
	SDG5: Gender equality	Opportunities for exploitation of water related EO-products can be explored
	SDG6: Clean water and sanitation	Water extent, water quality, aquatic ecosystem
	SDG7: Affordable and clean energy	Clouds, aerosols, wind, river discharge, water extent, water quality, water temperature

	SDG8: Decent work and economic growth	Water quality, water quantity
	SDG9: Industry, innovation and infrastructure	Water level, river flow, stream velocity
	SDG10: Reduced inequalities	Opportunities for exploitation of water related EO-products can be explored
	SDG11: Sustainable cities and communities	Flood extent
	SDG12: Responsible consumption and production	Water quantity, water quality, river discharge
	SDG13: Climate action	Water extent, water temperature, water level, lake ice cover, algal blooms, turbidity
	SDG14: Life below water	River discharge, plastics, water quality, algal blooms, eutrophication status
	SDG15: Life on land	Water quantity, water quality, flood, drought, aquatic plants/vegetations

	SDG16: Peace, justice and strong institutions	Opportunities for exploitation of water related EO-products can be explored
	SDG17: Partnerships for the goals	Opportunities for exploitation of water related EO-products can be explored
GCIs	Temperature and energy	Water temperature, water level, water extent
	Atmospheric composition	Water extent, primary production, Chl-a
	Ocean and water	Water extent, lake colour, water temperature, flood, drought, algal blooms
	Cryosphere	Lake ice extent, lake ice thickness

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