Review document and recommendation on the use of Copernicus products and services supporting water management

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List of Acronyms	
C3S	Copernicus Climate Change Service
CEMS	Copernicus Emergency Management Service
CLMS	Copernicus Land Monitoring Service
CMAP	CPC Merged Analysis of Precipitation
CMEMS	Copernicus Marine Environment Monitoring Service
EC	European Comission
EDO	European Drought Observatory
EFAS	European Flood Awareness System
EO	Earth Observation
ERCC	Emergency Response Coordination Centre
FD	Flood Directive
FLO1K	Consistent streamflow dataset at a resolution of 30 arc seconds (~1 km) and global coverage
FRMP	Flood Risk Management Plan
GCP	Ground Control Point
GDO	Global Drought Observatory
GHSL	Global Human Settlement Layer
GIS	Geographic Information System
GloFAS	Global Flood Awareness System
GMW	Global Mangrove Watch
NRT	Near real-time
RBMP	River Basin Management Plan
SAR	Synthetic-aperture radar
SDG	Sustainable Development Goal
SNAP	Sentinel Applications Platform
SWOS	Satellite-based Wetlands Observation Service
TSM	Total Suspended Matter
WFD	Water Framework Directive

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1 Introduction

1.1 Water-ForCE

The Horizon-2020 project Water-ForCE (Water scenarios For Copernicus Exploitation) will develop a Roadmap for Copernicus Inland Water Services
The Roadmap will contain:

- Analysis of user communities' landscape
- Analysis on how Copernicus water services can support policy development and monitoring of their implementation
- Gap analysis of the Copernicus water-related service portfolio
- Identification of future higher level biogeochemical products
- Technical requirements for future Copernicus sensors to improve the water-related service portfolio
- Proposal for organizing in situ measurement networks to validate Copernicus remote sensing and modelling products and to provide complementary data not collected by remote sensing
- Proposal on how to define relationships between Core Services and Downstream services
- Recommendation on the evolution of a water service (via the creation of a new service, or the improvement of water services under current Copernicus services, or through a better integration of water-related products)

The Water-ForCE project is coordinated by the University of Tartu (Estonia) with 20 participating organisations from all over Europe. It connects experts in water quality and quantity, in policy, research, engineering and service sectors.

This report is part of Work Package 3 (WP3) "Water quantity" whose overall objective is to provide insight on the Copernicus products (floods, drought, surface water extent, soil moisture, ice, …) and services supporting water management and modelling. It includes a gap analysis using existing knowledge by building a community of water quantity experts.

1.2 Purpose of the document

Water management is the process of planning, developing, and managing the quantity and quality of water resources across all water uses. It includes the institutions, infrastructure, incentives, and information systems that support and guide water management. Water resources management seeks to ensure there is sufficient water of adequate quality for different uses, as well as sustaining healthy water-dependent ecosystems and protecting the aesthetic and spiritual values of water bodies. Water resource management also entails managing water-related risks, including floods, drought, and pollution. The complexity of relationships between water and households, economies, and ecosystems, requires integrated management that accounts for the synergies and tradeoffs of water's great number of uses and values (World Bank, 2017).

In this deliverable, WP3 performed a literature review on the use of remote sensing products for water management, in order to identify ongoing applications, while gathering common gaps and recommendations by end users that can be considered towards the roadmap.

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1.3 Content of report

The report starts with an overview of different frameworks and directives that are crucial for water management in Europe and the world, and ways in which they are supported by remote sensing applications as a means of ensuring their compliance.

Later on, a summary of ongoing projects related to the Water Framework Directive, floods, droughts, climate policies and other actors is presented, to showcase examples of how remote sensing is actively being used for water management.

A gap analysis is then presented, in which the shortcomings of current remote sensing products were gathered from the literature review. Recommendations were then formulated based on the gaps found.

2 Remote sensing for water management

Water management encompasses the efficient and sustainable use of water resources for beneficial use and environmental protection. This covers a range of activities from operational management of existing resources, development of new resources, and planning and design of associated infrastructure, as well as early warning of hydrological hazards and management and reduction of risks (Sheffield et al., 2018).

While there is a broad consensus about the benefits of good water management, putting that knowledge into practice is usually easier said than done. To be able to make good water decisions, countries and governments need standardized ways to measure and monitor changes in water resources. They need an accurate account of their current resources—where, when, and how much—as well as an illustration of the potential changes caused by seasonal, natural, and climate-induced variability (García et al., 2016).

In-situ observation networks are fundamental but, they cannot always provide the spatial coverage and temporal frequency of the data needed for environmental assessment, and they are costly to maintain. Remote sensing, as a tool to cover larger areas and more frequently without heavy field personnel requirements, and its accessibility, reliability, and accuracy have improved dramatically in recent years (García et al., 2016).

The Copernicus programme for Earth observation represents a significant investment by the EU, justified by expected returns in public governance and private business. Copernicus is user- and policy driven (European Commission et al., 2020). The use of data collected from Copernicus' services for surveillance and operational monitoring has great potential to better standardize measures across Europe and the rest of the globe, enhancing both spatial coverage and frequency of monitoring of important variables (Carvalho et al., 2019).

3 Frameworks and directives for water management

The following section identifies the various frameworks and directives that address water management and for which information obtained through remote sensing and earth observation can be used to ensure their compliance. Where applicable, the current uses of remote sensing for the implementation of these initiatives are also mentioned.

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3.1 Water Framework Directive

The Water Framework Directive (2000/60/EC) (WFD) is a pioneering piece of legislation that aims to protect and enhance aquatic ecosystems and promote sustainable water uses across Europe (Carvalho et al., 2019; Chen et al., 2004). The WFD aims to harmonize European legislation by having Member States establish a programme for monitoring the status of all waterbodies larger than 0.5 km^2, in order to ensure future quality and quantity of inland waters (Alikas et al., 2015; Carvalho et al., 2019).

WFD requires monitoring of a) the volume and level or rate of flow to the extent relevant for ecological and chemical status and ecological potential and, b) the ecological and chemical status and ecological potential (Chen et al., 2004). The elements required to be monitored for surface waters are shown in Table 1.

Table 1. Monitoring requirements for surface water by the WFD. Source (European Parliament, 2000)

Surface water status	Biological elements	Hydromorphological elements	Chemical and physico-chemical
Rivers	Composition and abundance of aquatic flora, benthic invertebrate fauna and age structure of fish fauna	Hydrological regime: quantity and dynamics of water flow, connection to groundwater bodies River continuity Morphological conditions: river depth and width variation, structure and substrate of the river bed and, structure of the riparian zone	Thermal conditions, Oxygenation conditions, Salinity, Acidification status, Nutrient conditions, Specific pollutants
Lakes	Composition and abundance and biomass of phytoplankton, composition and abundance of aquatic flora, benthic invertebrate fauna and age structure of fish fauna	Hydrological regime: quantity and dynamics of water flow, residence time, connection to the groundwater body Morphological conditions: lake depth variation, quantity, structure and substrate of the lake bed, structure of the lake shore	Transparency, Thermal conditions, Oxygenation conditions, Salinity, Acidification status, Nutrient conditions, Specific pollutants
Transitional waters		Morphological conditions: depth variation, quantity, structure and substrate of the bed, structure of the intertidal zone Tidal regime: freshwater flow, wave exposure	
Coastal waters	Composition and abundance and biomass of phytoplankton, composition and abundance of aquatic flora, benthic invertebrate fauna	Morphological conditions: depth variation, structure and substrate of the coastal bed, structure of the intertidal zone Tidal regime: direction of dominant currents, wave exposure	
Artificial and heavily modified surface water bodies	The quality elements applicable to artificial and heavily modified surface water bodies shall be those applicable to whichever of the four natural surface water categories above most closely resembles the heavily modified or artificial water body concerned.		

The WFD encourages the active involvement of all interested parties in the implementation of the Directive and development of River Basin Management Plans (RBMPs). The RBMPs should include: mapping of the location and boundaries of surface and groundwater bodies, mapping of the ecoregions and surface water body types within the river basin, identification of reference conditions for the surface water body types, a summary of significant pressures and impact of human activity on

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the status of surface water and groundwater (i.e. estimation of point source pollution, estimation of diffuse source pollution, summary of land use, estimation of pressures on the quantitative status of water including abstractions, analysis of other impacts of human activity on the status of water), identification and mapping of protected areas, and map of the monitoring networks established (European Parliament, 2000).

Given the large number of water bodies, the directive constitutes a heavy financial burden if based only on traditional monitoring techniques (Alikas et al., 2015). The large expansion in monitoring required by the WFD has created pressure from governments on their regulatory agencies to reduce the costs of monitoring whilst maintaining coverage and effectiveness (Carvalho et al., 2019). Data available from satellite sensors support the requirements of the WFD on a long-term basis as new sensors are often designed such that data are comparable with their predecessors in terms of their spectral, temporal and spatial resolutions (Chen et al., 2004).

Concerning the specific domain of the WFD, several Copernicus services are active in distributing relevant products:

• ***Copernicus Land Monitoring Service (CLMS):*** The products mentioned below are available on the CLMS website and their spatial scale varies from global to local. these products are identified as useful for monitoring compliance with this framework: land use and land cover (change) maps, high-resolution water and wetness layers, lakes' surface water temperature and quality, identification of water bodies and water levels, lake ice and snow cover extent, soil water index, surface soil moisture, and expert products such as the water and wetness probability index (WWPI).

• ***Copernicus Climate Change Service (C3S):*** This service provides data and tools in order to prepare for climate variability and change in the water sector; for instance, they provide information on changes in the river discharges, droughts and floods, which are crucial for water management.

• ***Copernicus Emergency Management Service (CEMS):*** European Flood Awareness Service (EFAS) and the European Drought Observatory (EDO), together with the Rapid Mapping and Risk & Recovery Mapping services in relation to water.

• ***Copernicus Marine Environment Monitoring Service (CMEMS):*** In the specific case of water management, the most interesting products are the coastal ones.

3.2 Flood Directive

Flooding is a natural phenomenon that cannot be prevented. Some factors such as climate change and land use change can exacerbate the impacts of flooding, by reducing the land's ability for water retention. However, the impacts of flooding on human lives and infrastructure can be reduced. This is best achieved when measures are implemented within coordinated efforts at river basin scale.

The Flood Directive (FD) 2007/60/EC, established in October 2007, defines floods as areas that are temporarily covered with water, which otherwise would not be submerged under water; with the possible exclusion of floods caused by overflow from sewage systems. It defines a flood risk as the combination of the probability of occurrence of a flood and its potential impacts. The directive also indicates that flood risks can be considered as non-significant in case the impacted region is low in population and/or economic activity. In such circumstances, a risk assessment and evaluation of the need for further actions are to be analyzed (EUR-Lex, 2007).

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Flood risk management, by Member States, should be developed with best practice and best available technologies in mind without incurring excessive costs, this is where Earth Observation comes into play as a possible solution. Member States should also prepare Flood Risk Management Plans (FRMPs), indicate how guidelines of the Flood Directive are being implemented, and such information needs to be accessible to the public (EUR-Lex, 2007).

There is an overlap between the FD and WFD in terms of legal and planning processes. It is necessary to coordinate between measures implemented as part of both directives to ensure optimal cost benefit and coherent approaches taken. The FD explicitly emphasizes the need to abide by WFD guidelines. More specifically, the developed FRMPs should be integrated into RBMPs.

Copernicus is composed of a range of products relevant to floods such as flood monitoring, probabilistic flood forecasts, flash flood indicators, flood impact assessments and seasonal flood risk outlooks (European Commission, 2017). The Copernicus services with products that are useful for this directive are: CLMS, specifically water bodies and levels, C3S for the incorporation of climate variability in future planning, and the most important is Copernicus Emergency Management Service (CEMS) as it provides information for disaster emergency response as well as information for prevention, preparedness, response, and recovery activities. CEMS covers meteorological hazards, geophysical hazards, deliberate or accidental man-made disasters and humanitarian disasters.

CEMS consists of two main components:

- The **mapping component** of the service (CEMS - Mapping) has a worldwide coverage and provides accurate geo-spatial information derived from satellite remote sensing and is completed by available in situ or open data sources. The service also offers validation which is performed to continuously check the quality of outputs generated for both rapid and risk and recovery mapping whereby vulnerability assessment for people and building infrastructures can be requested. It can also be used as a tool in the development of recovery plans. The recovery process can also be tracked in time through images taken at select intervals. CEMS provides worldwide information before, during, and after a crisis. In addition, it offers digital and printed maps, and supports GIS analysis to facilitate decision making.
- The **early warning component** consists of three different systems: a) The European and Global Flood Awareness System (EFAS & GloFAS), b) The European Forest Fire Information System (EFFIS), which provides near real-time and historical information on forest fires and forest fire regimes in the European, Middle Eastern and North African regions, and c), The European and Global Drought Observatories (EDO & GDO), which provide drought-relevant information and early-warnings for Europe and globally. The latter will be discussed in the following section: Water Scarcity and Drought.

The European Flood Awareness System

The European Flood Awareness System (EFAS), operational since 2012, is a free and accessible service to EU & non-EU member states. It provides information on flood forecasts and flood impact forecasts. EFAS is designed for national and regional flood forecasting, and it informs the Emergency Response Coordination Centre (ERCC) about flood forecasts throughout Europe. The notifications are based on both the type of flood and probability of exceedance criteria. It is responsible for providing catchment scale information that is updated twice a day, and which has a 10 day lead time.

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Floods notifications are received by national authorities, which can access the EFAS portal in order to view more detailed information on the flood, which is needed for further analysis and response measures. These notifications are not available to the public, and EFAS is not tasked with the follow up with national/regional authorities. The aforementioned authorities are also not required to provide an acknowledgment of the receipt of a notification received from EFAS (Copernicus Emergency Management Service (CEMS), n.d.).

The Global Flood Awareness System

Since 2018, the Global Flood Awareness System (GloFAS) is an operational system for forecasting and monitoring floods across the world. GloFAS produces daily flood forecasts (GloFAS forecasts, since 2011) and monthly seasonal streamflow outlooks (GloFAS Seasonal, since November 2017). GloFAS data are freely accessible to all registered users through a dedicated web platform, the GloFAS map viewer, where a quick overview of the current and future hydro-meteorological situation, and of the ongoing and upcoming flood events is given (Copernicus, n.d.).

The aim of GloFAS is to complement relevant national/regional authorities and services, and to support international organizations in decision making and preparatory measures before major flood events (particularly in large trans-national river basins). GloFAS prediction only focuses on rivers and does not provide real-time forecast information on flash flood risk or coastal flooding, nor on inundated areas.

In 2021, a near real-time (NRT) satellite-based feature for the monitoring of floods was integrated into GloFAS. This component is based on the automated processing of Sentinel-1 SAR satellite data, based on three separate state-of-the-art satellite flood detection algorithms.

3.3 Water Scarcity and Drought

Water scarcity is a term that is used when water stress is caused by anthropogenic factors and when it has a mid-term duration (typically several months) or occurs frequently. Water scarcity and shortage are aggravated by drought. Drought is, in principle, a natural phenomenon, related to meteorological variability, but climate change adds an anthropogenic component to it (European Environment Agency, 2021).

Water stress affects 20% of the European territory and 30% of the European population on average every year, while droughts cause economic damage of up to EUR 9 billion annually and additional unquantified damage to ecosystems and their services. There is currently no EU directive or policy especially dedicated to drought but current legislation, sectoral policies, and instruments – binding or not – in the fields of water, agriculture, climate change, energy, industry, transport, nature protection, and biodiversity are partially or at least marginally related to drought management and can therefore support drought management policies (Global Water Partnership, 2020).

Whilst there is no European directive to specifically address drought, Article 1 of the WFD requires the Member States to 'promote the sustainable use of water resources based on the long-term protection of available water resources' and 'ensure a balance between abstraction and recharge of groundwater, with the aim of achieving good status of groundwater bodies'. Through this article, the WFD encompasses actions to prevent and counteract water stress. Member states are encouraged to develop and implement Drought Management Plans (DMPs) as part of the Communication, considered to be an annex to the RBMP according to Article 13.5 of the WFD (Bressers et al., 2016).

The European Drought Observatory

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The European Drought Observatory (EDO) is one of systems that comprises the CEMS early warning component. The European Commission Joint Research Centre helped to establish the EDO as part of ongoing efforts to integrate drought into policy. Since 2011, the EDO disseminates drought-relevant information and maps of indicators derived from a range of different data sources, including precipitation measurements, satellite measurements and modeled soil moisture content.

The EDO portal contains freely-downloadable drought information, graphs and time-series at European level. The EDO monitors severe drought events, and produces reports detailing the situation to better inform policymakers, thus supporting water management (Bressers et al., 2016).

The Global Drought Observatory

The Global Drought Observatory (GDO) generates drought-relevant information such as maps of indicators derived from different data sources (e.g. precipitation measurements, satellite measurements, modeled soil moisture content). The GDO includes a dynamic assessment of the risk of impact of drought for different sectors based on hazard, exposure and vulnerability by calculating several indicators derived from multiple products. The GDO is based on open web services and connects drought data providers and users from global to regional levels. In severe cases of drought events, it generates a detailed report of the situation.

3.4 European Green Deal

The European Green Deal is the overarching guiding document for the EU's "climate action plan", it is a strategy that aims to transform the EU's economy to ensure a sustainable future. Through the European Green Deal, the European Union aims to become a resource-efficient and competitive economy where there are no net emissions of greenhouse gasses by 2050, economic growth is decoupled from resource use and no person and no place is left behind. In short, the European Green Deal is ought to be a roadmap for making the European Union's economy sustainable (Copernicus, 2020). Earth Observation is crucial for assisting the monitoring of key environmental aspects, by using both in-situ observations and remote sensing. It will also allow tracking the evolution of climate change over time as well as the impact of measures, with the help of services such as the C3S (Thom, 2020).

The Copernicus programme and its services contribute to many key objectives of the EU Green Deal, some of them addressing issues related to water management.

- Supplying clean, affordable and secure energy: Data from C3S on past, present and future climatic conditions can be used to strategically plan and safeguard renewable energy projects and to estimate the balance between demand and production of power from existing hydro sources at different timescales. At longer timescales, data on the availability of water resources from CLMS and C3S are equally important to understand how hydropower and thermoelectric power generation will be affected by climate change (Copernicus, 2020).
- Preserving and restoring ecosystems and biodiversity: CLMS systematically produces a series of qualified bio-geophysical products on the status and evolution of the land surface. The products are used to monitor vegetation, the water cycle, the energy budget, and the terrestrial cryosphere. Hence, land aspects that can be impacted by and, in turn, impact climate change can be closely followed. The service contributes to climate policy by providing biophysical variables on the land condition to measure impact, resilience, and vulnerability. For this objective, Copernicus also offers a number of applications for the

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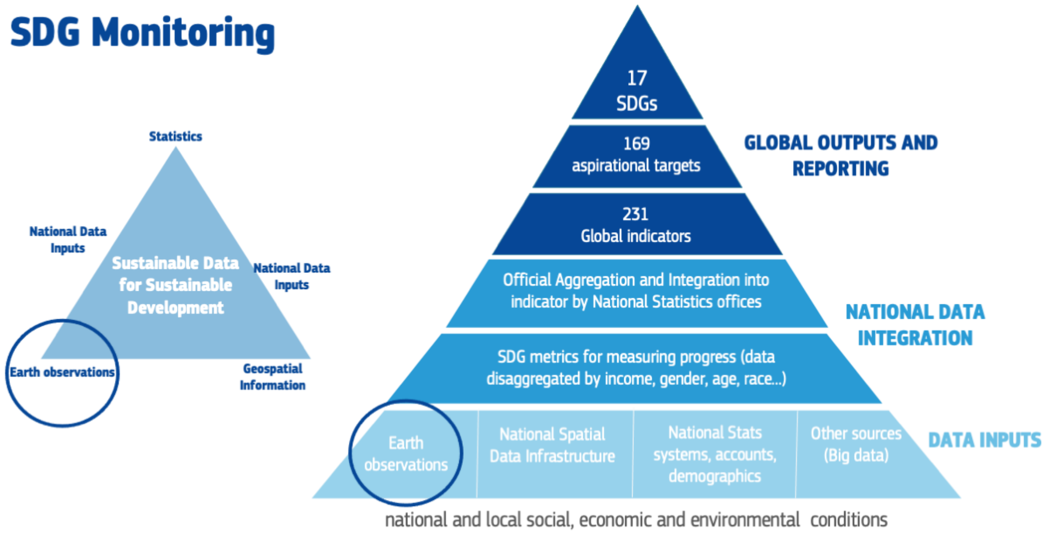
management of marine ecosystems and their biodiversity, however, this topic is beyond the scope of Water-ForCE (Copernicus, 2020).

In order to achieve the proposed short, medium and long term objectives, the EU Green Deal ought to aim for the cross-sectoral incorporation of more EO instruments in order to cover the macro areas of agriculture, forest management, biodiversity, fisheries, water management and smart mobilities. As previously mentioned, EO represents one of the most important tools for reaching a low carbon economy through the monitoring, analyzing, predicting and mitigating the human activity on natural resources (EARSC, 2021).

3.5 Sustainable Development Goals

In 2015, the members of the United Nations adopted a set of ambitious Sustainable Development Goals (SDGs) in the framework of the 2030 Agenda for Sustainable Development. These goals aim to address the world's most pressing challenges over the coming years, such as ending poverty, protecting the planet and ensuring prosperity for all. To measure and monitor progress towards the 17 SDGs and 169 associated targets, the UN established a global list of 231 indicators which serve as a common benchmark for regular reporting of overall progress (Copernicus, 2019).

The reporting and compliance with these indicators is challenging even to developed countries. There is a broad recognition that extensive requirements for supporting data involved in the measuring and monitoring are needed for so many indicators (Committee on Earth Observation Satellites, 2018). Therefore, EO offers unprecedented opportunities to modernize national statistical systems and improve the capacities of countries to efficiently track all facets of sustainable development.



Source: http://www.eohandbook.com/sdg/

Figure 1. EO as a source of data for monitoring and complying with the SDGs.

Some key benefits of using satellite EO data: a) makes the prospect of a Global Indicator Framework for the SDGs viable, b) has the potential to allow more timely statistical outputs, and c) provides improved accuracy in reporting by ensuring that data are more spatially-explicit. A number of satellite data characteristics are of interest for integration into national information systems: a) free

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and open data, b) large scale and coverage, c) consistency and comparability, d) continuity and time-series, e) complementarity with traditional statistical methods, and f) diverse measurements (Committee on Earth Observation Satellites, 2018; Copernicus, 2019).

Table 2. Summary of EO applications for SDG6 monitoring. Adapted from (ESA, 2020)

Target	Indicator	How can EO be used?	Potential data sources
6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all	6.1.1 Proportion of population using safely managed drinking water services	EO methods that can support this indicator mostly relate to assessment of water quality and land cover/land use around water catchments	GlobWetland II, Global Human Settlement Layer (GHSL), Global Surface Water Explorer, Satellite-based Wetlands Observation Service (SWOS), Copernicus Global Land Service
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	6.3.1 Proportion of wastewater safely treated 6.3.2 Proportion of bodies of water with good ambient water quality	EO-derived nutrient concentrations present in standing waterbodies. Parameters such as: Chlorophyll-a, Colored dissolved organic matter, Secchi disk depth (SDD), Turbidity, Total suspended matter (TSM), Water temperature (WT), Sea surface salinity (SSS)	Global Surface Water Explorer, Sentinel 2 and 3 (SNAP toolbox), Copernicus Global Land Service, CyanoLakes, EOMAP
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	6.4.1 Change in water-use efficiency over time 6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	EO technologies to quantify water use efficiency of vegetation	ESA CCI Land Cover, Global Map of Irrigation Areas (GMIA) of FAO, Global Irrigated Area Map (GIAM) of IWMI, Water Productivity through Open access of Remotely sensed derived data (WaPOR), Dry matter productivity (yield) and water bodies map from Copernicus Land Services, IrriSAT
6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	6.6.1 Change in the extent of water-related ecosystems over time	EO-based methods are mature for TSM (Total Suspended Matter) and chlorophyll concentrations, which can be used to report on some aspects of water quality of lakes and artificial water bodies but it's not a complete assessment of water quality.	Sentinel data (1,2 and 3) from the Copernicus Open Access Hub, Landsat, L-Band SAR satellite series operated by JAXA, Terra/Aqua MODIS, Visible Infrared Imaging Radiometer Suite (VIIRS), Global Surface Water Explorer, FLO1K, CMAP, GCP, GMW, Satellite-based Wetlands Observation Service (SWOS)

3.6 UNESCO Intergovernmental Hydrological Programme

The UNESCO Intergovernmental Hydrological Programme (IHP), founded in 1975 is the only intergovernmental cooperation programme of the UN system dedicated to water research and management, and related education and capacity development. It addresses national, regional, and global water challenges, by supporting the development of sustainable and resilient societies. Expanding a holistic understanding of water, improving technical capabilities, and enhancing human

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and institutional capacities are IHP's main tools. IHP's work supports sound, evidence-based water governance and decision-making drawing on transdisciplinary science and technology from other knowledge systems (Dogulu, 2022).

The strategic plan for IHP's 9th phase (2022-2029) was designed with the objective to maximize the support to Member States in attaining SDG6 and its related UN SDG6 Global Accelerator Framework, UN Water Decade for Action (2018-2028) and other water-related goals and targets by strengthening scientific knowledge, data availability and enabling informed decision making.

In addition, being the co-custodian of SDG 6.5.2 (Proportion of transboundary basin area with an operational arrangement for water cooperation) with the United Nations Economic Commission for Europe (UNECE) provides a unique opportunity to IHP to play a major role in identifying and implementing actions to help countries, within the framework of SDG6 and international conventions, achieve the required benchmarks pertaining the improvement of operational arrangements for water cooperation related to the management and conservation of transboundary aquifers (UNESCO IHP, 2022).

The role of EO in UNESCO IHP's strategic plan is highlighted in the first priority area: Scientific research and innovation. IHP will emphasize the use of new monitoring techniques, and in particular, the latest ICT technologies, remote sensing and big data, which offer exciting opportunities for observing and modeling hydrological processes across a wide range of spatial and temporal scales. IHP also highlights the development and sharing of new technologies such as EO, AI and IoT by the scientific community and service providers. These technologies are then communicated to stakeholders in the water sector and used for capacity strengthening to increase their use in hydrological planning and assessment, as well as in monitoring and distribution networks (UNESCO IHP, 2022).

The UNESCO IHP World Water Quality Portal showcases and demonstrates the potential of remote sensing and satellite Earth Observation to improve water quality monitoring towards sustainable water resources management. The portal's applications in world's basins aim to support basin organizations and national water and environment agencies for improved water quality monitoring towards sustainable water resources management. Its objective is to support basin organizations to better understand the water quality and ecological state of water resources, monitor the trend and evolution of water quality and pollution, and assess anthropogenic and climate change impacts on water resources (UNESCO, 2021).

3.7 Development Banks

Development banks constitute national or regional financial institutions that provide medium- and long-term capital for productive investment, often accompanied by technical assistance, for the development of countries. Below are some development banks that promote and invest in the use of EO for water management.

World Bank

The World Bank is committed to assisting countries meet their economic growth and poverty reduction targets based on the SDGs. Particularly, water resource management is tackled in SDG 6.5, but other SDGs and targets require water resource management for their achievement. Accordingly, the Bank has a major interest in helping countries achieve water security through sound and robust water resource management (World Bank, 2017).

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The Bank follows an integrated flood management agenda, which includes well-functioning early warning systems, infrastructure, and institutional arrangements for coordinated action to address increased variability and changes to runoff and flooding patterns (World Bank, 2017).

Below are two examples of applications supported by the World Bank:

- In Argentina, the Bank is enhancing flood protection and strengthening the capacity of the responsible institutions for integrated water resources monitoring and management in the Salado River Basin. This project created historical flood archives with flood detection algorithms used on MODIS, Landsat, and Sentinel data, implemented in Google Earth Engine, and accessible to agency staff through a user friendly Flood Monitoring and Analysis Dashboard. The spatial and temporal patterns of flood exposure over the past decades were used to extract spatial statistics on flood frequency and duration. In combination with population and socio-economic data, they form a basis for flood probability and vulnerability assessments (World Bank, 2019).
- Strengthening Water Security and Resilience in Mexico: ET and Crop monitoring at field level: The lack of budgets to monitor irrigation water use and agricultural practices is a reality across irrigation districts in Mexico. A remote sensing analysis of evapotranspiration (ET) and vegetation indexes (to monitor crop stage and crop type) over irrigation district Rio Colorado provided new understanding of the districts' dynamics (World Bank, 2019).

The World Bank Group's Open Learning Campus (OLC) accelerates development solutions by transforming global knowledge into actionable learning. By providing dynamic learning opportunities where diverse audiences can learn at their own pace and access the knowledge they need, the OLC equips individuals with the knowledge and capabilities to tackle the toughest development challenges. Technology is also changing the learning landscape. The OLC helps scale development learning by offering a comprehensive learning curricula with wider access and an enhanced learner experience. Through this platform they provide several trainings and webinars regarding the use of remote sensing for water management, thus providing some education oriented towards managers and stakeholders that could promote remote sensing applications.

Asian Development Bank

The Asian Development Bank (ADB) with the aim of advancing water security in Asia and the Pacific, has identified five key dimensions in its Asian Water Development Outlook 2020. All of which are closely related to the fulfillment of different SDG6 targets (and other SDGs), and at the same time, have the potential to benefit from the EO data that is available.

Apart from recognizing the usefulness and importance of remote sensing and EO as inputs to the proposed indicators and sub-indicators, the ADB also commits to investing in technological innovation measures such as remote sensing technologies to help mitigate unsustainable levels of water use. Likewise, it will encourage and scale up innovative technologies and digital solutions across the water sector, including smart network management and remote sensing (Asian Development Bank, 2020).

3.8 Humanitarian Assistance

Humanitarian action has rapidly adopted earth observation and geospatial technologies shaping them according to their needs, as promoted by large intergovernmental programmes such as Copernicus. Geohumanitarian action, defined as the integrated usage of earth observation and

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geoinformatics in support to planning and deploying of humanitarian aid, is a field where most assets of this technology can tap their full potential (Lang et al., 2020; Riedler et al., 2017).

Relating to water management, the applications include:

- Water availability: for the exploitation of local groundwater resources as a sustainable solution for the provision of sufficient potable water. Remote sensing can be employed for assessing the hydrogeological conditions. This obtained information is used as a critical asset to better organize vaccination campaigns, for medical, food-and-shelter logistics, and for drilling water wells.
- Infrastructure and water supply: Use of remote sensing to support the planning of water supply systems, to estimate water demands based on surrounding population distribution, to assess land cover and land use in the watershed in order to identify potential contamination risks, and support in the rehabilitation of water supply infrastructure after disasters
- Health and water access: The lack of resilience to the impacts of disasters often relates to limited access to health services. Remote sensing can be used to identify access to water sources and to estimate walking time to safe water sources
- Extreme events/disasters: Humanitarian assistance can benefit from early warning systems or flood maps in conjunction with surrounding population distribution to deploy resources and personnel necessary to handle these events.

The EO4HumEn+ research project is focused on EO-based services to support humanitarian operations: monitoring population and natural resources in refugee/Internally Displaced People (IDP) camps. It aims to develop and demonstrate innovative applications for satellite image interpretation and GIS to meet the diverse information needs of the humanitarian community. In particular, develop methods to monitor the population dynamics in urban settlements during crisis situations, improve the analysis capabilities of the large amounts of freely available Earth Observation data by implementing partly automated routines, and explore the satellite-based support of groundwater management practices (Universität Tübingen, n.d.). Some topics addressed in demonstrator products within the EO4HumEn+ project: Mapping of population around water points, support of water infrastructure rehabilitation, development of water body and flood monitoring system, support of groundwater exploration and water infrastructure planning (Lang et al., 2020).

3.9 Ongoing projects, products and frameworks using EO

WFD monitoring

- There are several active projects developing satellite products for WFD monitoring from ESA's Copernicus programme such as EOMORES, CYMONS, CHLO4MSFD and EUNOSAT (Carvalho et al., 2019).
- Service for Water Indicators in Climate Change Adaptation (SWICCA) offered readily available climate-impact data to speed up the workflow in climate-change adaptation of water management across Europe. The project served as a proof-of-concept for a Sectorial Information Service (SIS) on water management to C3S. The aim of the project was to bridge the gap between institutes who provide climate-impact data on one side, and water managers and policy makers on the other side.
- Earth2Observe aimed to integrate available global Earth observations via satellites and in situ data from ground stations with global hydrological and land surface models to perform a re-analysis and generate a comprehensive and consistent data set for global water resources. The project reconstructed time series of sufficient length (several decades) for key

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components of the water cycle, such as precipitation, evapotranspiration, soil moisture, groundwater and others. A key product of the project was the Water Cycle Integrator data portal, which provides all data sets online. The usefulness of the project outputs was demonstrated in selected case studies with the participation of local stakeholders.
- EuroGEO is the European component of the Global Earth Observation System of Systems (GEOSS) under the Group on Earth Observations (GEO) and focuses on coordination and scaling up user driven applications for Europe's benefit. Countries and citizens increasingly recognize the value of Earth observation tools for monitoring the implementation of such actions in a transparent way around the globe (European Commission et al., 2020).

Drought

- The European Drought Observatory for Resilience and Adaptation (EDORA) project aims to strengthen the EDO by improving drought risk assessment for different systems and at different scales, aggregating data on impacts on different sectors and fostering linkages and the establishment of drought observatories in Member States. The EDORA project aims to help build resilience and adaptation to drought risk for Member States. To this end, the project wants to create a database on drought impacts and a risk atlas covering the different sectors affected by drought (from agriculture to energy production, from inland navigation to domestic water supply). These products will contribute to improve the assessment of possible drought impacts and risk.
- Drought Watch: high-resolution evidence-based monitoring and early warning system, which includes remotely sensed drought indicators of soil moisture and vegetation conditions (Crocetti et al., 2020).
- InterSucho: advanced drought monitoring system for the Czech Republic and Slovakia. Combines the results of ground measurements, a dynamic water balance model and remote sensing methods. In terms of the quality and extent of input data, the methods used, the level of resolution and the way of verifying the entire system, this is a new chapter in drought monitoring in the Czech Republic. Drought monitoring is complemented by an independent analysis of the effects of drought on vegetation thanks to the confrontation of current and archival satellite images of the state of vegetation (with a resolution of 250 m) taken by the Aqua and Terra satellites - the MODIS system and processed in cooperation with MENDELU, CzechGlobe and Geografický Institute of Masaryk University. (Crocetti et al., 2020)

Irrigation

- Italy uses the National Information System for Water Management in Agriculture (SIGRIAN) platform for the monitoring of water volumes used for irrigation. This platform combines data from Google and Copernicus to obtain and process satellite information and earth observation data. All data collected and monitored in this system are useful to support planning, programming and management processes of policy making and enforcement, such as CAP common indicators, water pricing based on water uses, monitoring and evaluation of investment programs, supporting economic analysis for agricultural sector in the context of the WFD (Zucaro et al., 2020).
- The Italian National Institute for Environmental Protection and Research (ISPRA) has recently developed "BIGBANG – Nationwide GIS based regular gridded hydrological water balance on a regular grid", to evaluate the components of the water balance for the entirety of the Italian territory on a monthly scale. BIGBANG calculates the water balance equation on the

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1-km EEA grid by making use of: Total Precipitation, actual evapotranspiration, runoff, groundwater recharge, variation of the soil water content.

- InfoSequia: combines historical and up-to-date observations of satellite-based meteorological and agricultural drought indices with climate variability indices, to generate seasonal outlooks of water supply and crop yield failure alerts. These impact-based indicators are computed using a simple, robust and easily understandable statistical forecasting-modelling framework. By making use of multi-sensor, state-of-the art satellite data fully integrated with predictive models, InfoSequia-4CAST provides locally-specific, 3-6 months outlooks and warnings of crop yield and water supply failures to end users through a simple, intuitive user interface. The product is targeted to the needs of water managers who are looking to alleviate and mitigate impacts of forthcoming drought periods by taking strategic water management decisions, as well as humanitarian NGOs aiming to trigger ex-ante cash transfers with policyholders and farmer communities.
- IrriSAT: Italian irrigation advisory service based on satellite data (IrriSAT) is a weather based irrigation scheduling service which is used to inform farmers how much water their crop has used and how much irrigation they need to apply. Information is produced daily, and can work across large spatial scales. The IrriSAT methodology uses satellite images to determine the Normalized Difference Vegetation Index (NDVI) for each field, from which the plant canopy size can be determined and a specific crop coefficient (Kc) can be estimated. By combining Kc with daily reference Evapotranspiration (ET0) observations from a nearby weather station, the crop water usage can be determined and advice can be provided regarding the amount of irrigation to be applied.

SDGs

- For a policy-driven Copernicus service, it is necessary to help the policy DGs translate the EO-derived data into actionable information with indicators that can be used for monitoring. A prime example of such translation is given for the 2030 Agenda with the Sustainable Development Goals, where the Global Surface Water Explorer was accepted by the Expert Group on the SDG Indicator 6.6.1 for Water-related Ecosystems and creates a precedent of an Earth-observation driven SDG Indicator dataset (European Commission et al., 2020).

Development banks

- Earth observation for sustainable development (EO4SD) is an initiative by ESA and several development banks such as the World Bank, ADB, the International Fund for Agricultural Development, the Inter-American Development Bank and the European Investment Bank. This project aims at increasing the uptake of EO based information in regular development operations at the national and international level. Specifically, for water resource management the EO4SD will seek to demonstrate the benefits and utility of EO services in response to stakeholder requirements for water resources monitoring and management at local to basin scales.
- Earth Observation Services Supporting International Development Banks Projects (EOSID), and Expansion of EO Uptake in Developing Countries (EODAT). These projects addressed several EO based information services, each connected to one or more IDB funded infrastructure projects from multiple countries: Bolivia, Colombia, Guatemala, Guyana, Haiti, Mexico and Panama. These services were selected to cover a wide range of environmental issues that could be analyzed based on satellite data. The project demonstrated the benefits

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of EO technology as an operational support tool that enhances planning, implementation and monitoring of development projects.

Energy

- European Climate Energy Mixes (ECEM) is a proof-of-concept demonstrator that used climate and energy data to enable industry and policy makers to assess how well the energy supply in Europe can meet demand.

Water accounting and auditing

- **Water accounting** integrates hydrological processes with land use, managed water flows and the services that result from water consumption in river basins. Its objective is to achieve equitable and transparent water governance for all users and a sustainable water balance. The Water Accounting Plus (WA+) framework was developed to use open-access remote sensing based data for water accounting at the basin level. The framework combines the remote sensing based data with other available global data sets and ground measurements to produce standardized WA+ sheets supported by graphs, maps, and tables (IHE DELFT, n.d.).
- **Water auditing** is a process that places the findings, outputs and recommendations of water accounting into a broader framework comprising governance, institutions, public and private expenditure, legislation, services delivery and the wider political economy of specified domains (Batchelor et al., 2017). WaterSENSE provides water managers with a toolbox of reliable and actionable information on water availability and water use, anywhere in the world, in support of sustainable water management and transparency across the entire water value chain. The goal of WaterSENSE is to develop a modular, operational, water-monitoring system built on Copernicus Earth observation data. The first application is in the multi-climate Murray-Darling Basin in Australia, followed by validation in South Africa and the Netherlands (WaterSENSE, n.d.).

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4 Gap Analysis

A summary of the gaps mentioned during the literature review, categorized according to common areas, can be found in Table 3.

Table 3. Summary of gaps present on the use of EO for water management

Main category	Sub-category	Description
Data and products not meeting users requirements	Spatial resolution	Water management applications generally require information at the catchment scale. Sometimes, rescaling via statistical models or via assimilation into physical models is necessary, which require expertise from users.
	Temporal resolution	Temporal repeat (and cloud interference) of thermal infrared/optical retrievals hampers their use for daily scale decision-making of quantifying rapid changes.
	Latency	Latency is vital for some water management applications, in particular for flood warning (Sheffield et al., 2018).
	Continuity	Data record length and temporal consistency are a challenge for water management, which rely on long term and homogeneous time series to identify extreme events and calculate risk, especially for planning and engineering design.
		Use of remote sensing data is hampered by short mission lengths, and continuity issues for ongoing programs. Efforts are under way to stitch together data from multiple sensors, but careful intersatellite calibration is necessary, which is not a trivial task (Sheffield et al., 2018).
		Lack of confidence in the continuity of products discourages the investment of countries in applications dependent on the EO inputs.
	Use-specific indicators	Lack of remote sensing data for assessing anthropogenic activity and the association with drought propagation/termination. Need for a range of drought indicators (West et al., 2019).

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Lack of integration	With in-situ data	Water managers demand product accuracies specific for "their" water body. Remote sensing algorithms and global products, however, are validated at specific study areas and sensors. Therefore, adaptation of existing algorithms is often required (Dörnhöfer & Oppelt, 2016). Validation of retrievals, and potentially calibration of the models, is therefore vital. Unfortunately, this is not done as comprehensively as one would like due to the lack of in situ data.
Lack of integration	With in-situ data	Individual retrievals are generally validated against in situ data that have a limited footprint or are region specific, and in isolation from other variables of the water balance. Limited assessment to date of the consistency among remotely sensed variables at scales relevant to water management shows a range of errors across variables and non-closure of the water budget when combined (Sheffield et al., 2018).
Lack of integration	Long-term	Some satellite sensors are research instruments and there is no guarantee that the same (or sufficiently similar) instruments will be launched again to replace aging or failed instruments (AghaKouchak et al., 2015).
Lack of integration	Multi-platform	Drought specific: combining multiple data sets to improve drought detection, given the variety of satellite observations, remote sensing allows development of an integrated multi-index composite drought assessment framework, which are in their infancy and more research is needed. Improving early drought detection using satellite observations by exploring different products that could be applied for drought monitoring.
Lack of integration	Multi-platform	Complementarity of information sources by integrating multiple data streams (Crocetti et al., 2020).
Lack of integration	With other tools/models	Integration of EO with artificial intelligence for water management applications is needed (Crocetti et al., 2020).
Lack of integration	Between Copernicus Services	The fact that similar products are spread over different Services makes it very difficult to find the exact product that optimally meets your requirements.

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	In policy frameworks	EO data products are currently underused in water resources management. One key reason for this appears to be the lack of familiarity among the water management community with available EO products and the ways in which they can be used to address water-related issues. There is a lack of understanding of what the Copernicus products actually are and can do. The link between the Copernicus services and the policy cycle is still fragile, and efforts should go in that direction in the future.
		For a policy-driven Copernicus service, it is necessary to help the policy DGs translate the EO-derived data into actionable information with indicators that can be used for monitoring. The financing of projects such as the Proof of Concept (PoCs) are good for demonstrating the wide use that can be made of Copernicus data, and how it can be presented to water managers. However, many of these projects close their platforms once the projects are completed, making it impossible for users to access the databases already created.
	Formats	Community acceptability, clearly defining basic elements such as cartographic color schemes, summarization of retrieved information, and data formats is one of the most important parts of the data-to-information process (AghaKouchak et al., 2015).
		Users prefer ready products and algorithms which are integrated into software or toolboxes going along with technical assistance. Remote sensing agencies should provide products that are ready for analysis, in standardized formats. (Dörnhöfer & Oppelt, 2016; Sheffield et al., 2018).
		There are different set-ups of the data portal from each Copernicus Service, which makes it difficult for users to access the available data.
	Between stakeholders	Effective dialogue between scientists and managers and stakeholders is necessary. There is a perceived disconnect between research carried out in academic institutions and management agencies, even within the same country (Sheffield et al., 2018).
Lack of confidence in EO/remote sensing data	Uncertainty quantification/communication	Lack of uncertainty information may prevent integration of satellite data into decision making and operational applications (AghaKouchak et al., 2015).
		Lack of communication regarding the accuracy assessment of products and the data used for validation.
	Long-term application	Lack of guaranteed support and commitment to invest in this field is a major roadblock for establishing consistent, long term remote sensing data records necessary for accurate anomaly detection against a historical baseline (AghaKouchak et al., 2015) .

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	In-situ data used for validation	An essential problem in validating remote sensing indicators, is the upscaling of discrete in situ measurements to the spatial measurement of a sensor. High accuracies are demanded for remote sensing products whereas in situ measurements intrinsically are accepted as correct. Standardized uncertainty assessment are necessary for both remote sensing indicators and in situ data (Dörnhöfer & Oppelt, 2016).
	Atmospheric corrections	Atmospheric correction specific for water bodies instead of using those developed for land or used in-situ reflectance measurements (Dörnhöfer & Oppelt, 2016).
Lack of capacity	Technical	Providing data in near real time is a challenge to the supporting computational and network infrastructure
		Lack of infrastructure and resources from water managers across the globe to access EO data
	Human	The provision of specific trainings and methodologies focused on water management (rather than generic remote sensing techniques) is needed as it will encourage its adoption and will increase the quality of its applications (Chen et al., 2004). Not only the open exchange of the data is fundamental, but also providing the appropriate training in the use of existing and upcoming remote sensing technologies.
		Lack of skills/need of proper training to translate research products into retrospective products that can be used for design and planning, or operational products that can be used for day-to-day management and early warning (Sheffield et al., 2018).
	Long-term analysis	Capability of extending multidecadal observations to develop robust drought climatologies remains uncertain, challenge on ensuring that the data volumes are well managed and that the data records are easily available to the science community and the public, requires major hardware infrastructure to store and serve the data, and data professionals to process, curate and disseminate the data.

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5 Conclusions

Despite the plethora of remote sensing products on water management that are available, there is a limited use of RS products for water management. There is a need for more suitable products to better monitor the status of the water bodies (eg from future SWOT missions) and to provide more data on human interactions in the water cycle, especially in data scarce areas. At the same time, the biggest bottleneck is to make the data FAIR (Findable/Accessible/Interoperable/Reusable).

Our analysis highlights the importance to better harmonize the data, to involve and train the end users and to integrate the use of remote sensing data in water policy implementations.

6 Recommendations

Products:

- New satellite products to better characterize the state of the water bodies and its evolution (e.g. on seasonal to annual basis) should be proposed. Improved Digital Elevation Models (DEM) and Bathymetries are basic core requirements for the coastal zone. The monitoring and short- and long-term prediction of sea level close to the coasts should be improved. This is required for a wide range of applications (flooding, coastal erosion, coastal zone management).
- Better processing (i.e. specific algorithms) of satellite observations is required to improve the quality of water products. New approaches require checks on comparability with the existing nationally-approved and intercalibrated assessment methods, which can be challenging.
- A key challenge historically has been the shorter-term availability of remotely sensed data for inclusion in drought monitoring practices when compared to traditional in-situ measurements. Opportunities for effective drought monitoring will continue to expand with new approaches to "blend" data such as the fusion of Landsat/Sentinel data. Sensor blended data product ESA CCI (Climate Change Initiative). GLDAS Global Land Data Assimilation. Utility of Google Earth Engine in rapidly calculating evaporation/evapotranspiration, the platform has still yet to be fully utilized for wider/integrated drought monitoring approaches at global scale (West et al., 2019).
- Guaranteeing QA/QC and standards: Creation of particular standards and reference datasets
- Provide data from future/planned SWOT missions to better monitor river flows and lake storage.

Better integration/harmonization:

- It would be easier for end users and water managers if the platforms through which Copernicus data is accessed were similar, or if all information could be accessed from the same platform. In this way the wide range of information available for each particular use could be known.
- Stronger interfaces and integration between the Services and downstream monitoring systems should be developed. This includes harmonization and standardization issues (e.g. formats, quality assessment methods, documentation, data distribution) and of the use of consistent and improved inputs.
- Products from national/member states monitoring systems could be made available through CMEMS, CLMS or Copernicus (e.g. DIAS) data portals (coproduction EU & Member States)

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- Links/interfaces with the European Marine Observation and Data Network (EMODnet) portals and activities (e.g. bathymetry, seabed habitats, chemistry) should be reinforced.
- Enabling full integration of different datasets: not only high-quality data but also enabling easy combination of different datasets. Data and Information Access Services (DIAS) should be the vehicle for this. JRC Earth Observation Data and Processing Platform (JEODPP) could have a role.
- Ensure an integration with other RS products from various agencies (e.g. NASA)

End user involvement:

- There is a need for the exchange of information between remote sensing scientists and various organizations (national and international policy makers, government agencies and both legal and scientific bodies that are involved in the development and implementation of water policy) (Chen et al., 2004). There need to be feedback loops between the end users and Copernicus services to understand users' needs and how the Services can cater to them.
- An outstanding need is to identify and exploit the synergies between the services and investigate the possibility of producing and distributing tailored products vis-a-vis the needs of the end users and their applications (European Commission, 2018). Also, the cost of delivering data in interpretable products and effectiveness in terms of pressure-response relationships and confidence in classification needs to be scrutinized (Carvalho et al., 2019).

Link with EU policies:

- Member States are encouraged to improve and expand monitoring and assessment tools to ensure a statistically robust and comprehensive picture of the status of the aquatic environment. As a consequence, future Copernicus sensors should be able to provide the necessary observations to properly measure that. Moreover, additional research is needed in order to a better uptake of EO-based indexes for characterization, impact assessment and prediction of droughts.
- Integration of remote sensing in monitoring frameworks such as the WFD (Apostolaki et al., 2019) in order to encourage its use amongst water managers and stakeholders
- Elaborate status monitoring at water body level that include water quantity and quality data integrated with local sensor data.
- Setting the example at top level: Support at higher hierarchical level for a deeper involvement of the different DGs is needed for a smooth transition including also EO data for enhanced policy planning and implementation.
- Remote sensing should be suggested as an information source in frameworks such as the WFD guidance documents in order to promote its use amongst water managers

Sustainability of products/platforms:

- The platforms for Proofs of Concepts (PoCs) are not available once the projects are finished, not being able to be a resource or inspiration for future applications, leaving room for duplicated efforts.

Capacity development:

- Increasing communication, information and training: The water sector is highly differentiated and multifaceted. The set of requirements emerging from it have to be considered when looking at the next generation of Copernicus as well as near-term service evolutions. The

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provision of appropriate training in the use of existing and upcoming remote sensing technologies is fundamental to ensure a correct use of it.

Flood specific:

- Based on the recent flood events in Europe in July 2021, better coordination and communication as well as training on the Copernicus products and services are needed in order to limit the adverse consequences of such events. When asked about the matter, Philippe Dierickx, the director of hydrological management (DGH) within the Public Service of Wallonia revealed that the DGH authority did not check the data available in EFAS due to a lack of training for engineers in using the tool, as well as a need to test and validate the data it provides. He also indicated that information provided by EFAS can be very difficult to interpret (Amies, 2021). In order to build trust and increase the likelihood of the utilization of Copernicus products and services, it is important to compare the data it provides with local data. Establishing a protocol whereby competent national and regional authorities in the European Union acknowledge the receipt of warning notification sent from the European Flood Awareness System could also be helpful in building a direct line of communication, and requesting additional information as needed. Lastly, a detailed review of Copernicus products in relation to the requirements of the Flood Directive and the Water Framework Directive could be very useful in identifying gaps and adaptations to the currently available products.
- Special focus on application potential should be put on areas that don't have their own forecasting systems

Drought specific:

- There is a lack of information on vertical moisture profiles in vegetation and soil (SMAP mission offers a unique avenue for future research in this direction, but more is needed). Microwave-based vegetation indices, microwave-based monitoring provides information on live aboveground biomass and canopy density are needed.

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