Recommendations for development of Earth Observation services

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Publishable Executive Summary

This report translates the Earth Observation (EO) experience of SOS-Water into recommendations for the further development of operational water monitoring products and services, with a primary focus on Copernicus. SOS-Water develops a framework for assessing the Safe Operating Space of water resources in large river basins under changing climatic, environmental and socio-economic conditions. Within this framework, EO contributes spatially distributed information on water-system states and processes and supports hydrological modelling, calibration, benchmarking and indicator assessment, while remaining one component of a broader system that also depends on in situ observations, models and management information.

The report builds on the Water-ForCE roadmap for Copernicus water services (Kutser et al., 2024) and complements this strategic perspective with application-level evidence from SOS-Water. The assessment draws on the SOS-Water EO data inventory and gap analysis, integration of EO with the Integrated Water Modelling System (IWMS), development and testing of EO prototypes, Safe Operating Space (SOS) indicator requirements, and internal expert elicitation. Together, these sources provide evidence on where existing EO products already support basin-scale applications and where important limitations remain.

The SOS-Water experience shows that the main challenge is not simply the availability of satellite observations and products. Operational value depends on whether products resolve the relevant processes at appropriate spatial and temporal scales, are supported by representative calibration and validation data, transfer reliably beyond their development domain, correspond to the quantities required by models and indicators, and can be accessed and maintained consistently over time. The prototype work illustrated these issues across different applications, including lake ice monitoring, riverine suspended sediment, snow water equivalent, altimetry, surface water temperature and crop water productivity. It also highlighted persistent information gaps, particularly for river monitoring, human water use, groundwater-related quantities and snow conditions in complex terrain.

The report therefore recommends that future EO water services be developed around the concept of fitness for intended use. Scientific accuracy remains essential, but operational readiness also requires suitable scale and sampling, validation aligned with the intended application, transparent uncertainty and documentation, efficient programmatic access, and sustained product stewardship. At the same time, further development is needed for water-information products that remain insufficiently represented in current operational services and for stronger integration of EO with in situ monitoring, hydrological models and decision-relevant information. These recommendations are formulated primarily towards Copernicus, but are also relevant to other operational EO service and product providers and to the wider GEOSS framework.

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Abbreviations

API	Application Programming Interface
AWIC	Aggregated Water and Ice Cover
CCI	Climate Change Initiative
CDOM	Coloured Dissolved Organic Matter
CLMS	Copernicus Land Monitoring Service
CWATM	Community Water Model
EBV	Essential Biodiversity Variable
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
ECV	Essential Climate Variable
EO	Earth Observation
EOP	Earth Observation Prototype
EOV	Essential Ocean Variable
ERA5	ECMWF Reanalysis version 5
ESA	European Space Agency
ET	Evapotranspiration
EWV	Essential Water Variable
FAIR	Findable, Accessible, Interoperable and Reusable
FAO	Food and Agriculture Organization
GEOGLOWS	GEO Global Water Sustainability
GEOSS	Global Earth Observation System of Systems
GRACE	Gravity Recovery and Climate Experiment
GRACE-FO	GRACE Follow-On
IWMS	Integrated Water Modelling System
KGE	Kling-Gupta Efficiency
LWQ	Lake Water Quality
MAGIC	Mass-change And Geosciences International Constellation
NASA	National Aeronautics and Space Administration
NGGM	Next Generation Gravity Mission
OPENDAP	Open-source Project for a Network Data Access Protocol
PCR-GLOBWB	PCRaster Global Water Balance
SDG	Sustainable Development Goal
SIGPAC	Sistema de Información Geográfica de Parcelas Agrícolas
SOS	Safe Operating Space
SPM	Suspended Particulate Matter

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1 Background

1.1 Context and purpose

SOS-Water develops a framework for assessing the Safe Operating Space (SOS) of water resources in large river basins under changing climatic, environmental and socio-economic conditions. The project combines hydrological modelling, biodiversity and ecosystem assessment, stakeholder engagement, Earth Observation (EO) and decision-support approaches. Within this framework, EO provides spatially distributed information on water-related processes and conditions and can support model forcing, parameterization, calibration and benchmarking. However, EO represents only one component of the wider observation and modelling system required for basin-scale SOS assessment.

This report translates the EO-related experience of SOS-Water into recommendations for the further development of long-term observation frameworks, with a primary focus on Copernicus. Copernicus is central because it provides the main operational European framework for sustained EO services and supplies a large share of the EO products relevant to water monitoring, modelling and decision support globally. It therefore represents a key pathway through which EO-derived information enters operational water-resource assessment and management in Europe and beyond. The report does not aim to provide a comprehensive review of EO requirements for the water sector. Instead, it examines what the practical application of EO within SOS-Water reveals about the information needed for basin-scale modelling, SOS indicators and decision support, and focuses on the areas where current observation products and services show the most significant gaps or limitations.

GEOSS, the Global Earth Observation System of Systems, is not addressed as a separate target in this report. Unlike Copernicus, it primarily provides a framework for coordinating and connecting distributed EO rather than providing an operational portfolio of water products and services. In addition, it is currently operating under substantial resource constraints and funding uncertainty, including reduced Secretariat capacity and uncertainty over future U.S. contributions. For these reasons, the recommendations are formulated primarily towards Copernicus. Nevertheless, the requirements identified for EO-based water monitoring remain directly relevant to other operational EO services and product providers, as well as to the GEOSS framework.

A central reference is the Water-ForCE (Water Scenarios for Copernicus Exploitation) Roadmap for Copernicus water services (Kutser et al., 2024), which was published during the course of SOS-Water. Water-ForCE assessed the existing Copernicus water portfolio, identified major bottlenecks and explored alternative pathways for future service development. It therefore provides the strategic service-level foundation for this report and an important evidence base. SOS-Water complements this perspective with application-level evidence from EO data assessment, model integration, prototype development and basin-scale SOS indicator requirements.

The overall objective is to identify actionable requirements for future EO-based water services. These concern not only conventional product characteristics, such as spatial and temporal sampling, continuity, validation and uncertainty characterization, but also whether EO-derived information can

be effectively combined with in situ observations and models to support the assessment of water-system states, pressures and management-relevant indicators and ultimately the safe operating space.

1.2 Evidence base and scope

The report draws on four closely related sources of evidence from SOS-Water. First, the EO data inventory and gap assessment (Brechbühler, 2025; Brechbühler et al., 2023) identified available products and broader observation needs across relevant water variables. Second, the development and testing of selected EO prototypes provided practical examples of where EO could address specific information gaps and where limitations remained (Brechbühler et al., 2026). Third, the assessment of EO integration with the Integrated Water Modelling System (IWMS) provided evidence on the suitability of EO products for model forcing, parameterization, calibration, benchmarking and indicator assessment (Simons et al., 2025). These technical findings are interpreted together with the SOS indicator work developed across the project, which defines the quantities and processes that ultimately need to be characterized for basin-scale Safe Operating Space assessment.

A fourth source of evidence is an internal SOS-Water expert elicitation conducted with project partners working across hydrology, modelling, biodiversity, water management, decision support, coordination and EO. The survey captured project-internal perspectives on relevant Essential Water Variables (EWVs), Water-ForCE bottlenecks, information gaps and priorities for improving EO-derived water information. It is used as expert feedback from within the project rather than as a representative survey of the wider water sector.

The EO prototypes addressed a selected subset of the broader observation gaps identified in SOS-Water. They focused on applications that were technically feasible and sufficiently mature to be implemented within the project timeframe and available resources, and therefore do not represent the full range of EO needs relevant to the SOS framework. The recommendations developed here consequently draw not only on prototype experience, but also on the wider gap assessment, SOS indicator requirements and modelling needs.

2 Strategic reference framework for Copernicus Water services

2.1 The Water-ForCE roadmap

Water-ForCE was a Horizon 2020 Coordination and Support Action that developed a Roadmap for the future development of Copernicus water services (Kutser et al., 2024). It started from the observation that Copernicus already provides a substantial amount of water-related information, but those relevant products are distributed across different Copernicus Services, portals and processing chains. This fragmentation makes it difficult for users to access and combine information describing the water cycle as a connected system.

The roadmap assessed how Copernicus could better support water-related policy, management, research and downstream applications. Its evidence base included stakeholder engagement, inventories of existing products, assessments of satellite and in situ observation capabilities, and analyses of modelling and data assimilation needs. Water quantity and water quality were both considered, with particular attention to inland and near-coastal waters.

Water-ForCE found that the water quantity portfolio was comparatively broad, including products related to precipitation, snow and ice, soil moisture, water storage, drought and hydrological conditions, but heterogeneous in terms of spatial and temporal resolution, validation, uncertainty information and suitability for operational use. The operational inland water quality portfolio was considerably more limited, with several variables of interest to water management, ecosystem assessment and policy either unavailable or only available through research or regional applications.

The report's main conclusions are that improved support for the water sector requires more than additional individual products. It also requires stronger coordination across Copernicus Services, closer integration of satellite observations with in-situ monitoring and modelling, improved validation and uncertainty information, and clearer links between EO-derived variables and the information required by water users.

2.2 Water-ForCE bottlenecks, scenarios and recommendations

Water-ForCE identified eight bottlenecks that limit the uptake and operational impact of Copernicus water services shown in Figure 1. These bottlenecks span different parts of the observation and service chain. Some concern the underlying measurement infrastructure, particularly satellite capabilities and in situ observations. Others concern product quality, validation and compatibility with policy or monitoring requirements. A further group relates to service organization, accessibility, awareness and the institutional position of water within Copernicus.

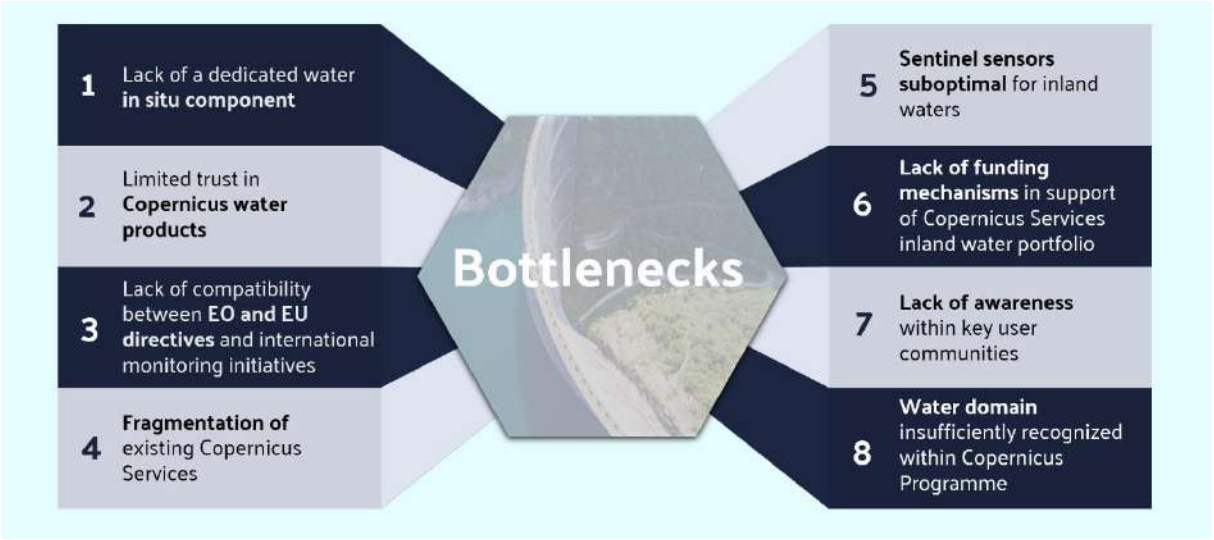

Figure 1: Bottlenecks limiting the uptake and operational impact of Copernicus water services, as identified by Water-ForCE (from Kutser et al., 2024).

Water-ForCE also examined four scenarios for the future organization of Copernicus water services. Business as Usual assumed continued development within the existing service structure. A Water Thematic Hub would provide a more visible thematic entry point to existing products, primarily improving discovery and access. Water as a Virtual Service would introduce stronger coordination across the existing Copernicus structure, while Water as a Copernicus Core Service would establish water as a dedicated service domain. The latter two scenarios were considered better suited to addressing structural issues such as coordination, in situ integration and systematic product development.

The associated recommendations followed the Copernicus value chain from data provision and product development to service delivery and downstream uptake. They included improving observation capabilities for inland waters, strengthening in situ calibration and validation, expanding water-quality and water-quantity products, improving interoperability and analysis-ready data, and reinforcing links between EO, modelling and user communities.

These recommendations provide the strategic baseline for this report. They identify where the Copernicus water-service framework needs to evolve, but they are necessarily broad because they target programme, service and institutional actors. SOS-Water complements this perspective by examining what these general needs imply when EO information is used within basin-scale modelling, indicator assessment and decision-support workflows.

2.3 From service-level roadmap to SOS-Water evidence

This report uses the Water-ForCE Roadmap as its strategic reference and interprets it through the practical experience of SOS-Water. Water-ForCE addresses the evolution of Copernicus water services from the service and programme perspective; SOS-Water contributes from the application perspective of a basin-scale Safe Operating Space framework. Figure 2 illustrates this relationship. Water-ForCE provides the strategic foundation through its assessment of benefits, bottlenecks, service scenarios

and recommendations. SOS-Water contributes evidence from the IWMS, stakeholder- and science-driven SOS indicators, EO data and gap assessments, EO prototypes and internal expert feedback. These two perspectives are brought together in this deliverable to derive more specific requirements for improved future Copernicus water services.

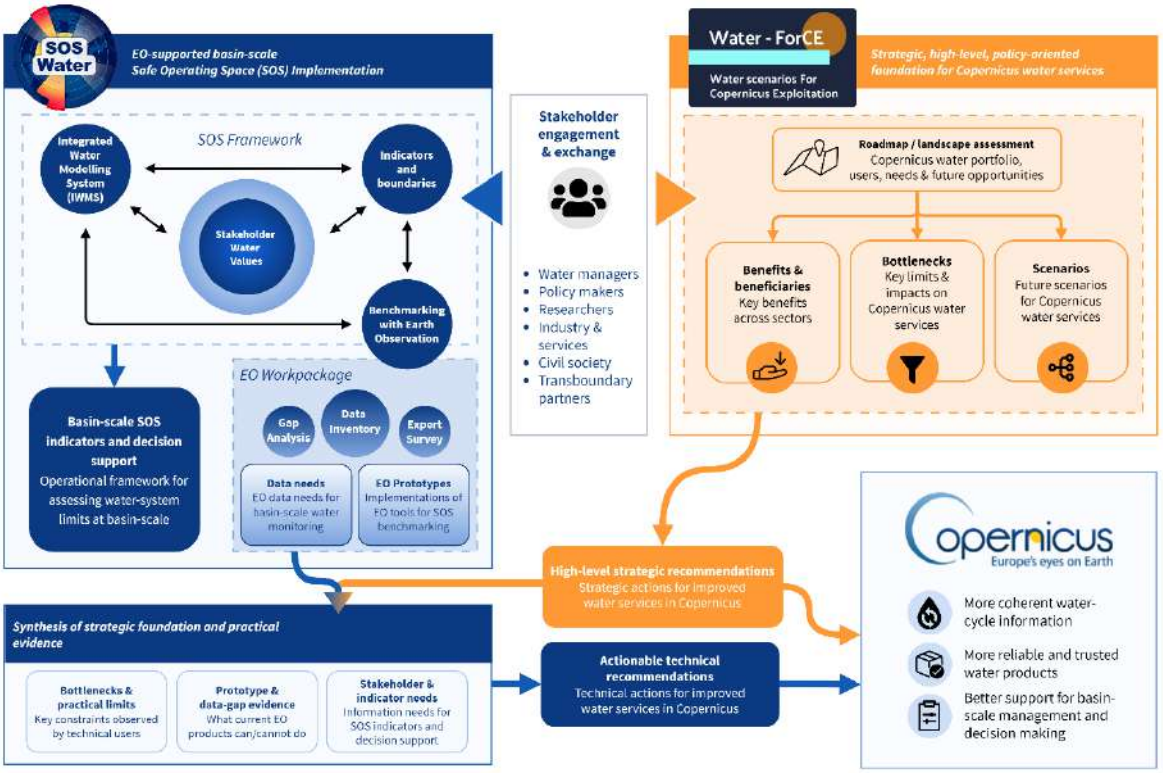

Figure 2: Conceptual overview of how the Water-ForCE strategic roadmap and the SOS-Water evidence base inform recommendations for future Copernicus water services.

The SOS-Water perspective is particularly relevant because basin-scale assessment requires information on interacting physical, ecological and human processes. Water availability, demand, water quality, ecosystem response and management interventions cannot be considered independently. EO products are therefore evaluated not only according to their technical specifications, but according to whether they can contribute to the models and indicators required to understand these interactions.

Chapter 3 develops this application-level perspective by identifying the information required for basin-scale SOS assessment, examining the relationship between SOS indicators and EO-observable quantities, and assessing where current EO products and the SOS-Water prototypes address these needs or leave important gaps. The subsequent chapters use this evidence to identify the main bottlenecks and derive actionable and technically driven recommendations.

3 EO information needs for basin-scale SOS assessment

The information requirements of a Safe Operating Space assessment extend beyond the variables that can currently be retrieved from satellites. SOS-Water assesses water systems through a combination of hydrological modelling, ecological and water-quality information, human water use, stakeholder-defined priorities, and indicators describing different water functions. EO therefore contributes to the SOS framework as one part of a wider observation and modelling system. Its value depends not only on whether a variable can be observed from space, but on whether the resulting information can help characterize the processes, pressures, and management responses that determine the state of a basin.

This distinction is important because many of the quantities relevant to water-resource management are either only indirectly observable from space or cannot be observed from satellites at all. Satellite observations are particularly strong for spatially distributed surface properties and changes, but hydrological retrievals frequently depend on algorithms, auxiliary information or models, and their spatial and temporal scales do not necessarily correspond to those required by basin-scale models or management applications. These limitations are well established in the wider hydrological EO literature (McCabe et al., 2017). More recent reviews similarly emphasize the complementary roles of EO, in situ observations and hydrological models rather than treating satellite products as substitutes for conventional monitoring (Lubczynski et al., 2024).

The SOS-Water EO data inventory (Brechbühler et al., 2023) and gap assessment provide a useful starting point for examining this mismatch. It reviewed 188 project-relevant datasets. Most of the identified products offered broad geographical coverage, 83% were global, and 68% had a nominal spatial resolution of approximately 1 km or finer. For the large-scale hydrological modelling framework, approximately daily temporal information and kilometer-scale spatial information were used as useful reference requirements. However, nominal product specifications alone were found to be an incomplete measure of suitability. Effective observation frequency can be substantially lower because of cloud cover, satellite revisit, retrieval failure or missing data, while nominal spatial resolution does not necessarily reflect the scale represented by the retrieved quantity.

The following sections therefore move from the broader water variables required to describe the basin system (Section 3.1), through their relationship with the actual SOS indicators used in the project (Section 3.2), to the ability of current EO products and the SOS-Water prototypes to provide the required information in practice (Section 3.3).

3.1 Essential Water Variables for basin-scale water assessment

The concept of EWVs provides a structured way of identifying the water-related variables that are most important for understanding, monitoring and managing water systems. It follows the broader “essential variables” approach used across Earth observation communities, including Essential Climate Variables (ECVs), Essential Ocean Variables (EOVs) and Essential Biodiversity Variables (EBVs). In this context, an essential variable is not defined by whether it can be observed directly from a satellite, but by its relevance for describing a system and supporting decisions, together with the feasibility of obtaining sufficiently useful observations. Within the GEOGLOWS project, EWVs have been developed

as a user-oriented framework addressing the availability, quality and use of water resources and the need for timely, spatially appropriate and accessible observations for water management.

This EWV framework is strongly oriented towards freshwater resources and water management, although its development has also explicitly considered inland and coastal waters. For SOS-Water, this emphasis is appropriate because the Safe Operating Space framework primarily concerns freshwater availability, quality, ecosystem functioning and human water use within large river basins. Coastal and transitional processes remain relevant where they are connected to basin dynamics, for example through sediment delivery, salinity intrusion or delta processes.

SOS-Water used this essential-variable logic to connect basin-scale water challenges with the quantities needed to characterize them. Rather than adopting a single fixed list, the relevant information domains were determined by the processes, pressures and management questions represented in the SOS framework. These include meteorological forcing; water storage and fluxes; surface water dynamics; groundwater; snow and cryosphere processes; water quality and sediment transport; land and ecosystem state; and human water use and management. Figure 3 provides an overview of these information domains and the principal variables considered in SOS-Water and tries to give an expert estimate on the extent they can be observed directly from EO. The variables differ considerably in the extent to which they can be observed directly from EO, derived through proxies, or require integration with models, in situ observations or management data.

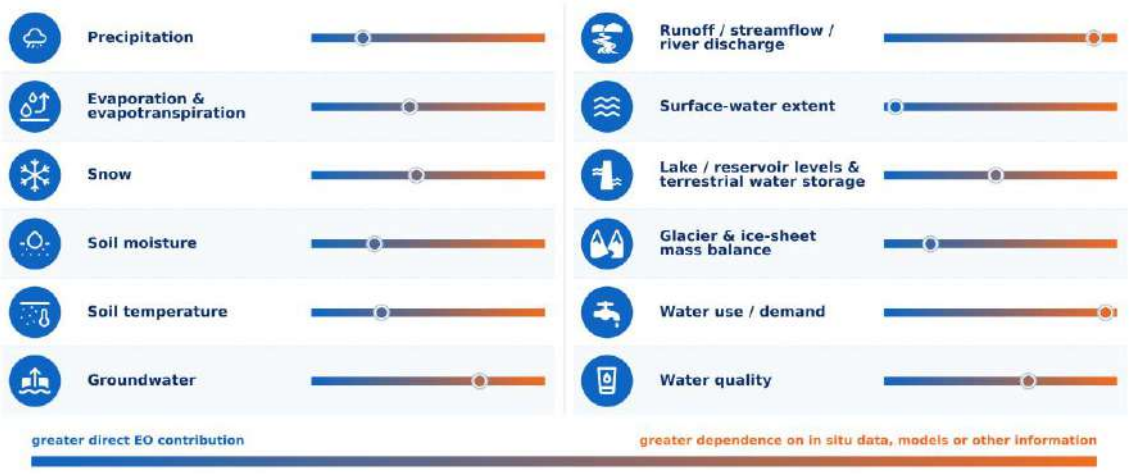

Figure 3: Primary Essential Water Variables and their degree of EO observability

This broad information base is necessary because the Safe Operating Space of a managed river basin cannot be characterized from water availability alone. Human interventions alter the storage, movement, timing and quality of water and thereby affect ecological and societal functions. The water-function framework underpinning SOS-Water considers water in terms of supply, carrier, state, productive and regulatory functions, recognising that pressures on one component of the water cycle can propagate across sectors and scales (Falkenmark & Wang-Erlandsson, 2021).

The EO gap assessment showed, however, that observation capability differs substantially between these information domains. Some variables can be observed relatively directly from space, but remain constrained by spatial resolution, temporal sampling, sensing depth or retrieval uncertainty. Other quantities can only be inferred indirectly through EO-derived proxies or model integration, while several management-relevant variables cannot presently be quantified from satellite observations alone. Table 1 summarizes the principal EO-relevant needs and limitations identified for SOS-Water.

Table 1: Main EO-relevant information needs and observation gaps for basin-scale SOS assessment.

Information domain	EO-relevant variables	Specific need or limitation identified in SOS-Water
Meteorological forcing	Precipitation, temperature, radiation, water vapour	Precipitation products contain spatial and temporal gaps and remain less reliable for snowfall, extremes, high latitudes and complex terrain. Basin modelling requires temporally continuous forcing rather than intermittent observations.
Evapotranspiration and soil water	ET, surface soil moisture, crop water stress	ET retrievals differ between products and methods and can be too coarse or computationally demanding for basin and irrigation applications. Satellite soil moisture primarily represents shallow layers and does not directly provide root-zone storage.
Surface water dynamics	Water extent, lake/reservoir level, river level, flood extent, streamflow	Water extent and level are comparatively well observable, but **streamflow is not directly measured from space**. Conversion of water level or width into discharge requires hydraulic information, rating relationships or modelling, while revisit frequency can miss short-lived events.
Groundwater and total water storage	Groundwater storage change, terrestrial water storage, groundwater level	Gravimetric observations provide valuable large-scale storage-change information but at spatial scales far coarser than individual aquifers or management units. Groundwater levels and abstractions remain dependent on monitoring wells, administrative records and models.
Snow and cryosphere	Snow cover, snow water equivalent, snowmelt, lake/river ice	Snow cover is readily mapped, but snow depth, density and therefore SWE remain considerably more uncertain. Long-term observations of river and lake ice are fragmented. Snow information also needs to correspond to the representation of snow processes within hydrological models.
Water quality and sediment	Surface water temperature, turbidity, suspended particulate matter, chlorophyll-a, CDOM	EO is strongest for optically active properties and surface temperature. Nutrients, many pollutants and chemical variables are not directly observable. Inland-water retrievals are sensitive to atmospheric correction, mixed pixels, water optical complexity and the availability of suitable in situ validation data.

Information domain	EO-relevant variables	Specific need or limitation identified in SOS-Water
Land and ecosystem state	Land cover, vegetation productivity, phenology, habitat extent	Long EO archives provide strong information on land-cover and vegetation change, but simple indices do not necessarily represent ecosystem condition or water-related ecological function. Indicator interpretation therefore generally requires additional ecological or model information.
Human water use and management	Irrigated area, crop type, water demand, abstractions, allocations, reservoir operations	EO can identify irrigated areas, crop conditions and ET-related consumption, but withdrawals, allocations, operating rules and many sectoral demands cannot be directly quantified. These remain a major information gap for managed-basin assessment.

The gaps identified in SOS-Water are consistent with limitations reported in the wider hydrological EO literature (García-García et al., 2026). Satellite soil-moisture observations, for example, primarily represent the near-surface layer and do not directly resolve root-zone storage; gravimetric observations provide valuable information on terrestrial water-storage change but at spatial scales substantially coarser than individual aquifers or management units; snow water equivalent remains difficult to retrieve robustly; and streamflow generally has to be inferred from remotely sensed water levels, widths or other observations in combination with hydraulic relationships or models (Lubczynski et al., 2024; McCabe et al., 2017) .

Water quality presents a related but distinct challenge. EO can substantially improve the spatial coverage of inland-water observations, particularly for surface temperature and optically active constituents such as suspended matter, chlorophyll-*a* and coloured dissolved organic matter. However, retrieval performance depends on sensor characteristics, atmospheric correction, water optical complexity and suitable in situ validation. Many chemically or biologically important quantities, including nutrients and several pollutants, are not directly observable from space (Odermatt et al., 2012; Palmer et al., 2015; Tyler et al., 2016). This separation between observable water-quality proxies and the variables ultimately required for management is particularly relevant because water quantity and quality processes are closely coupled through discharge, residence time, sediment transport, dilution and temperature (Ellis et al., 2024).

A particularly important gap for SOS-Water concerns human water use and management. Water demand and consumption emerged as highly relevant both in the project's technical assessment and in the internal expert elicitation, yet they are among the least directly observable components of the basin system. EO can provide valuable information on irrigated area, crop type, evapotranspiration and vegetation condition, but translating these observations into actual abstractions, allocations or operational water use requires models, administrative information and independent observations. Satellite-based estimates of irrigation water use can therefore be highly valuable, but their

uncertainties become especially important when the information is used at management or regulatory scales (Foster et al., 2020).

The resulting observation requirement is therefore broader than the provision of additional satellite products. Basin-scale SOS assessment depends on a combination of direct EO observations, EO-derived proxies, in situ measurements, modelled quantities and water-management information. The relevant question is consequently not only whether an EWV can be observed from space, but how well available observations can constrain the processes and indicators required to assess the Safe Operating Space. Section 3.2 develops this link from water variables to the SOS indicator framework.

3.2 From SOS indicators to EO-relevant observables

SOS-Water does not assess a basin directly in terms of EWVs. The Safe Operating Space is evaluated through case-specific systems of indicators and thresholds that represent relevant water functions, sectors and stakeholder concerns. Indicator selection therefore provides the link between describing the physical water cycle and producing information that is meaningful for basin management.

The final indicator systems developed for the four SOS-Water case studies illustrate how heterogeneous these information requirements are. In the Danube, the indicator set included flow alteration, river connectivity, aquifer recharge, water-supply reliability, habitat suitability, navigation and nitrogen and phosphorus concentrations. In the Júcar, relevant indicators included groundwater levels, reliability of water supply for different users, crop water stress and fish-habitat-related flow conditions. The Mekong system included hydropower generation, sediment transport, reservoir greenhouse-gas intensity, agricultural water deficits, fish catch, flood-pulse characteristics and fish diversity. In the Rhine, the final system covered multiple streamflow and hydrological-variability metrics, baseflow and snowmelt contributions, droughts and floods, navigation, reservoir storage, surface- and groundwater abstractions, irrigation withdrawal, water temperature and fish habitat.

These indicator systems make two points particularly clear. First, there is no single EO variable set that represents the SOS of a basin. The relevant variables depend on basin processes and stakeholder priorities. Second, many indicators are a number of analytical steps away from the quantity recorded by a satellite. A satellite may observe surface reflectance, radiance, microwave backscatter or water-surface elevation; an EO processor converts this to variables such as turbidity, snow cover, soil moisture or water level; a hydrological or ecological model may then transform or combine those variables; and only then can an SOS indicator and its position relative to a threshold be calculated.

The EO–IWMS integration assessment therefore classified the relationship between SOS indicators and EO into three broad groups outlined in Table 2.

Table 2: How Earth Observation contributes to the quantification of SOS-Water indicators.

Relationship to EO	Examples from SOS-Water	Interpretation
Strong/direct EO support	Reservoir and surface-water levels/extent; flood extent; sediment/SPM; land-cover change;	EO can provide a spatially explicit observation closely related to the quantity of interest,

Relationship to EO	Examples from SOS-Water	Interpretation
	surface water temperature; snow/glacier indicators; erosion/subsidence	although ancillary data and validation may still be required.
Partial or proxy support	Ecological status; salinity intrusion; drought severity; nutrient status; agricultural water demand; habitat condition	EO observes a related property or proxy, but the SOS indicator requires additional modelling, in situ observations or interpretation.
Not directly quantifiable with EO	Streamflow at control points; groundwater level in individual aquifers; groundwater abstraction; pollutant loads; hydropower generation; fish catch	EO may constrain related processes, but the indicator itself depends principally on models, in situ monitoring, administrative data or sectoral information.

The distinction between water level and streamflow is a useful example. Satellite altimetry can now provide increasingly valuable river and lake water-level observations, and water extent can be observed using optical or radar imagery. However, discharge at a control point—the quantity used by many SOS indicators—requires information on channel geometry, hydraulic relationships or modelled flow. Satellite observations can therefore improve the estimate without themselves being the indicator. A similar distinction applies to groundwater: large-scale storage change can be detected by gravimetry, but this does not provide groundwater levels or abstraction volumes at the aquifer and management scales represented in SOS indicators.

Water-quality indicators show the same translation problem. Surface water temperature, suspended sediment, turbidity and chlorophyll-*a* estimates can be derived from EO with varying confidence, whereas total nitrogen and phosphorus, and many other pollutants or ecological-status indicators cannot be derived from the electromagnetic signals that EO satellites can sense. Satellite observations can nevertheless provide useful proxies and spatial context. The wider inland water literature similarly stresses that EO is complementary to—not a replacement for—in situ water quality observations, especially in optically complex waters and when the variable of management interest is not directly optically active (Ellis et al., 2024; Palmer et al., 2015; Tyler et al., 2016).

This distinction is particularly important for the SOS framework because EO observations primarily describe historical and present conditions, whereas the Safe Operating Space assessment also evaluates future conditions under climatic and socio-economic scenarios. Within SOS-Water, the IWMS provides this forward-looking capability. EO contributes by improving model inputs, parameterization, calibration and independent benchmarking, thereby increasing confidence in the models used to calculate future SOS indicators. This role is consistent with the broader modelling literature, which identifies climate forcing, parameters, boundary conditions and observations used for model calibration or assimilation as the main pathways through which remote sensing contributes to integrated hydrological models (Lubczynski et al., 2024).

The EO requirement from an SOS perspective is therefore not simply that an observation corresponds to an indicator by name. The observation must resolve a relevant component of the process underlying the indicator, at scales and with uncertainties that permit it to constrain the model or assessment. This provides the basis for evaluating the products and prototypes considered in the following section.

3.3 EO data needs, available products and prototype evidence

The SOS-Water EO inventory (Brechbühler, 2025) showed that a substantial portfolio of EO products already exists for many components of the water cycle. The main limitation is therefore not a general absence of satellite data, but a mismatch between available products and the information required for basin-scale modelling, Safe Operating Space (SOS) indicators and decision support. Depending on the variable and application, available products may be too coarse or intermittent, represent only part of the required quantity, depend strongly on local calibration data, or require substantial processing and model integration before they become operationally useful.

The accompanying EO gap assessment (Brechbühler et al., 2023) identified these limitations across a considerably broader set of variables than could be addressed through prototype development. Important gaps concerned, among others, streamflow, groundwater state, snow storage, inland water quality, human water use and management. The prototype work therefore focused on a selected subset of needs for which further methodological development was relevant to SOS-Water and technically feasible within the project timeframe. The prototypes should be interpreted as test cases along different EO-to-decision pathways rather than as a complete representation of the observation needs identified by the project.

A useful way to interpret the prototypes is to place them against the existing operational landscape. In several cases, Copernicus or other operational services already provide a related product, but the SOS-Water application exposed limitations in spatial scale, temporal continuity, transferability, model compatibility or the distance between the EO observable and the final water-management quantity. Table 3 therefore compares four representative SOS-Water prototypes with the closest operational reference products. The comparison is intentionally selective: it is used where the prototype provides a clear technical lesson, rather than forcing a one-to-one Copernicus comparison for every prototype.

Table 3: SOS-Water EO prototypes in relation to existing operational EO capabilities

Prototype	***Operational reference***	***Operational limitation / gap***	***SOS-Water contribution***
Suspended Particulate Matter (SPM) Mapper for Rivers (EOP1)	No dedicated Copernicus riverine sediment product	Operational water quality products are largely limited to lakes; comparable products for systematic riverine water quality monitoring are absent.	Developed river-specific sediment retrievals for the Mekong and combined EO observations with discharge information to characterize sediment dynamics and estimate sediment transport.
Lake and River Ice Mapper (EOP2)	Copernicus Water and Ice Cover (WIC/AWIC)	Operational pan-European ice information is available, but independent testing at Alpine lakes revealed classification noise and limited robustness when transferred to unseen lakes.	Developed a high-resolution multi-sensor ice product from Sentinel-1/2, Landsat and ECOSTRESS, supported by >40,000 webcam observations, with model development and evaluation optimized towards generalization.
Crop Water Productivity Mapper (EOP5)	Copernicus CLMS Evapotranspiration	Operational EO provides key biophysical information such as evapotranspiration, but not the crop water-productivity information required to relate consumptive water use to agricultural production.	Combined EO-based water use and productivity information with crop, land use and local contextual data to derive spatial crop water productivity for the Júcar basin.
Snow Water Equivalent (SWE) Downscaling (EOP6)	Copernicus CLMS SWE	Operational SWE provides broad and frequent coverage, but its kilometer-scale spatial resolution remains coarse relative to snow variability and increasingly high-resolution hydrological models. Moreover, mountainous terrain is masked out.	Downscaled daily SWE from coarse-resolution input to 500 m using topographic information and in situ observations, bringing SWE information closer to basin and model scales.

Validation must demonstrate transferability

The EOP2, focusing on ice mapping, was developed with the main goal to produce a high-frequency, spatially consistent record of lake ice cover over the European Alps by combining Sentinel-1/2, Landsat and ECOSTRESS observations, fusing optical, thermal and radar data. Calibration and validation relied on more than 40,000 webcam-based observations from 15 Alpine lakes. Although this reference set included lakes of different sizes and altitudes, the resulting model was intended to be applied far beyond this limited sample to more than a thousand lakes, making robust transfer to previously unseen lakes a key methodological requirement. Model development was therefore structured around strict leave-one-lake-out cross-validation throughout, including model tuning, training and performance evaluation. In each fold, the evaluation lake was excluded entirely from model development, so that model selection itself was optimized for generalization to unseen water bodies rather than in-distribution performance. A semi-supervised labelling approach further enabled training information to be generated from thousands of satellite scenes while preserving this lake-level separation.

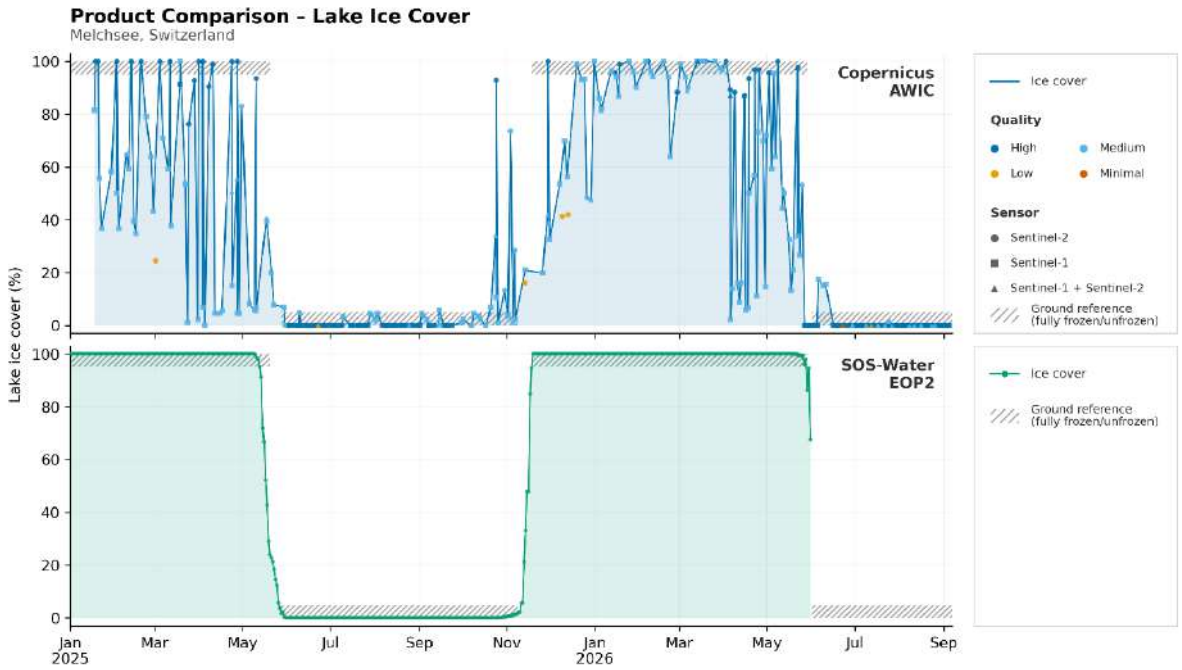

Figure 4: Product comparison of Copernicus Aggregated Water and Ice Cover (AWIC) with the SOS-Water Earth Observation Prototype 2 (EOP2) on an independent out-of-distribution reference dataset from Melchsee, Switzerland. Both products represent multi-sensor based EO models that classify lake ice cover. The line fitted to AWIC ice cover uses only high and medium quality datapoints as suggest for best use. A key requirement for these products are a high temporal frequency and accurate capture of freeze onset and offset dates for ice phenology assessments.

Such strategies are key when developing models that are expected to generalize across diverse and extensive study areas and waterbodies. This becomes particularly apparent when comparing EOP2 with the Copernicus Aggregated Water and Ice Cover (AWIC; (European Union Copernicus Land Monitoring Service, 2025)) product, which provides operational, pan-European lake- and river-level ice cover information. Despite high reported validation metrics, inspection of the products' time series revealed clear noise and generalization issues, particularly in observations derived from Sentinel-1. To

substantiate this, an independent comparison was carried out for the Swiss Alpine lake Melchsee using independent webcam-based reference information shown in Figure 4. AWIC showed frequent short-term fluctuations and abrupt shifts in estimated ice cover that were inconsistent with the observed seasonal lake state, whereas EOP2 reproduced freeze-up, the stable ice-cover period and break-up much more coherently. The comparison shows that training and validation strategies should be selected and reported to reflect the intended operational use case and claimed application domain. Evaluation designs that do not represent the spatial, temporal or environmental scale over which a product is subsequently provided can yield overly optimistic performance estimates. Transferability should therefore be tested explicitly across representative conditions within the claimed product domain. Where robust performance cannot be demonstrated, the product scope should be restricted accordingly and remaining limitations and uncertainty made explicit.

River monitoring remains underrepresented in operational EO services

EOP1 was developed to map suspended sediment dynamics in the Mekong. For large river basins, such information is particularly relevant because rivers act as major transport pathways for sediment, while dams and other artificial barriers can strongly alter sediment connectivity and redistribute sediment loads along the network. EO can substantially improve the spatial description of these dynamics between generally sparse conventional monitoring stations, helping to identify basin-scale changes that are difficult to capture from point observations alone, particularly in transboundary basins. Our experience also showed, however, that riverine SPM retrieval requires dedicated calibration and validation, as relationships between optical signals and measured sediment load can vary between locations due to differences in sediment and water type properties. Continuous sediment-flux estimates additionally require discharge information and methods to bridge data gaps in tropical wet seasons.

More broadly, the prototype highlighted a gap in the current operational EO portfolio. Copernicus provides established products for several lake variables, including water quality and surface water temperature, whereas comparable products for systematic river monitoring are absent. This is particularly important because rivers are major freshwater habitats and transport corridors for sediment, heat, nutrients and pollutants, while also being strongly affected by dam construction, flow regulation, land-use change and pollution. The SOS-Water EO work on rivers, including sediment (EOP1) and surface water temperature (EOP4), therefore points to the need for dedicated river-focused EO products, with retrieval and validation approaches designed explicitly for river environments.

Spatio-temporal resolution and coverage should reflect hydrological process scales

The Snow Water Equivalent (SWE) downscaling prototype addressed the mismatch between the spatial scale of available SWE information and the strong variability of snow storage in mountainous catchments. Starting from daily ERA5-Land SWE at approximately 9 km resolution, the SOS-Water workflow combined topographic information and in situ observations to generate daily SWE estimates at 500 m resolution. This is particularly relevant as large-scale hydrological models, such as PCR-GLOWB 2.0, are increasingly moving towards hyper-resolution simulations at around 1 km (van

Jaarsveld et al., 2025). At these scales, coarse SWE information can become a limiting input, particularly in mountainous regions where elevation and terrain strongly control snow accumulation and melt. The prototype therefore demonstrates the value of bringing observation-based SWE information closer to the spatial scale at which hydrological processes are increasingly represented in models.

More generally, EO product development needs to consider spatial resolution, temporal frequency and geographic coverage together with the scale of the intended application and monitored processes. SWE is a major seasonal water store in snow-dominated basins, and its spatial distribution can strongly influence the timing and magnitude of runoff. The existing Copernicus SWE product provides an important operational basis at 5 km, but it is derived from passive microwave retrievals that are provided only for non-mountainous regions. For snow dominated basins such as the Upper Danube and the Rhine, the operational product therefore offers no information in the areas that generate most of the snowmelt, and the SOS-Water prototype started from ERA5-Land rather than from the Copernicus product for this reason. The remaining gap is consequently both a coverage gap in complex terrain and a scale gap relative to hydrological models moving towards kilometer-scale resolution.

Decision-relevant information requires additional processing and context

Copernicus has recently expanded its evapotranspiration portfolio with global actual evapotranspiration at 300 m on a 10-daily step, separated into soil evaporation and canopy transpiration, and explicitly positioned as support for reporting on water-use efficiency under SDG 6.4.1. For agricultural water management, however, evapotranspiration alone does not answer how efficiently water consumption is translated into crop production or how different crops and irrigation schemes perform. The Crop Water Productivity Mapper therefore went a step further by combining EO-based evapotranspiration with biomass production, the regional SIGPAC land use dataset and ERA5-Agro forcing in place of the coarser default climate inputs, deriving net biomass water productivity per cropland category and irrigation scheme for the Júcar. This provided a quantity that is more directly relevant for hydro-economic assessment and irrigation management than evapotranspiration alone.

More generally, the prototype illustrates a recurring gap between variables that can be observed from EO and the information needed for water-management decisions. Human water use, demand, abstraction and allocation remain difficult to observe directly from space and usually have to be inferred by combining EO with models, land-use and crop information, statistics and other local data. Decision-relevant products therefore often require an additional layer of integration and interpretation beyond the underlying EO variable. The challenge for future services is not only to improve observation of physical water-cycle variables, but also to develop robust pathways for translating them into quantities that better represent human water use and management. A takeaway for Copernicus is that the missing element is not evapotranspiration itself, but the biomass term and the crop and irrigation context needed alongside it. Publishing these on the same grid and calendar would allow water productivity to be derived consistently rather than reconstructed locally for each application.

3.4 Internal expert elicitation: priorities and blind spots

To complement the technical assessment, an internal expert elicitation was conducted in person with SOS-Water project partners to capture perspectives on EO information needs, bottlenecks and improvement priorities for basin-scale Safe Operating Space assessment. Participation varied between questions, with up to 15 respondents. The results are interpreted as project-internal expert feedback rather than as a representative survey of the wider water sector.

The respondent profile indicated that the feedback mainly reflected the perspective of EO users rather than EO developers. The role question allowed multiple selections; 13 respondents provided 17 role selections. Water management and decision support was the most frequently selected area of expertise, followed by hydrology and modelling, biodiversity and ecosystems, coordination/project management and EO. The results therefore provide insight into how EO-derived information was perceived by partners who use, interpret or integrate such information in modelling, indicator development and decision-support workflows.

The ranking of EWVs provided a complementary perspective on the information needs discussed in Sections 3.1 and 3.2. As shown in Figure 5, water demand and consumption were selected most frequently (10 of 12 respondents), followed by streamflow (9), surface and groundwater levels (8) and water quality (7). Precipitation was selected by only five respondents, but all five ranked it first. This reflects the application-specific nature of basin-scale information needs: some variables are broadly relevant across the SOS framework, whereas others are particularly important for specific hydrological processes or management questions.

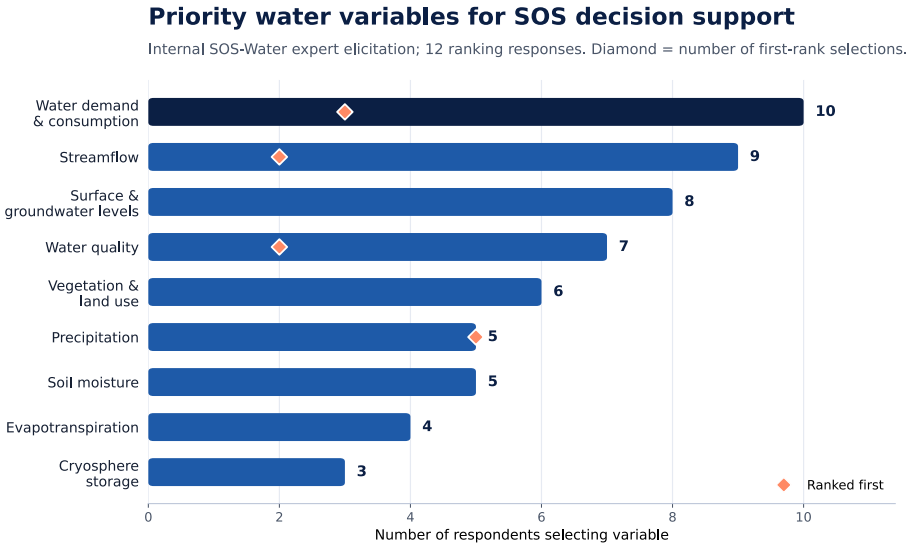

Figure 5: Expert survey results for prioritization of Essential Water Variables decision support.

The assessment of the Water-ForCE bottlenecks showed a similarly clear priority pattern. The lack of an in-situ water component was rated as the most significant bottleneck, with a mean score of 4.2 out of 5; 12 of 15 respondents (80%) rated it 4 or 5 (Figure 6). Sentinel sensors being suboptimal for inland waters and lack of awareness within key user communities followed with mean ratings of

approximately 3.5. In contrast, limited trust in Copernicus water products received the lowest mean rating (2.4). The responses therefore point less towards a general distrust of EO and more towards practical limitations in the observation system surrounding EO products, particularly the availability of reference observations, suitable sensor characteristics and alignment with user needs.

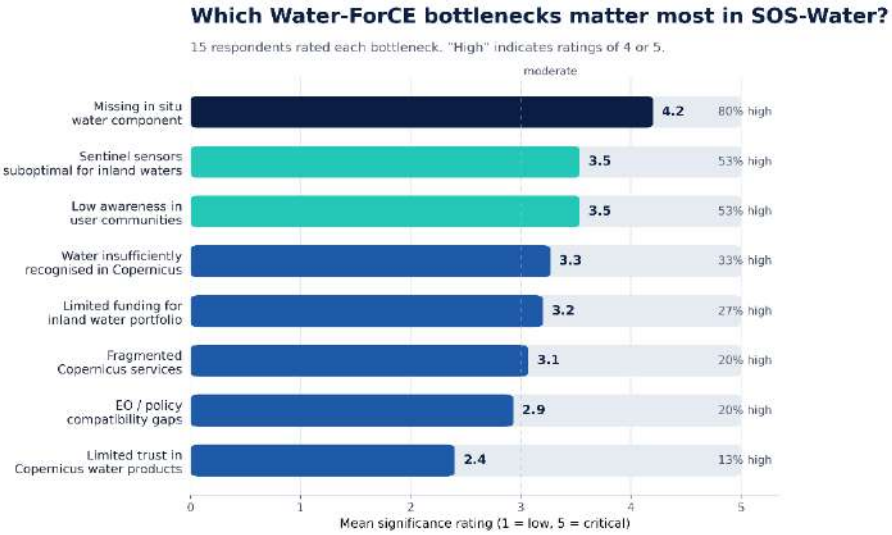

Figure 6: Expert survey results for perceived significance of Water-ForCE bottlenecks for SOS-Water.

The open-ended responses provided further detail on these limitations. Partners highlighted insufficient long and continuous time series, missing in situ observations for calibration and validation, limited information on human water use and management, and the lack of products corresponding directly to model-relevant quantities such as root-zone soil moisture, groundwater, snow water equivalent, discharge and reservoir inflow and outflow. Other responses referred to fragmented data portals, processing requirements and insufficient documentation. These observations broadly reinforce the gaps identified through the EO inventory, SOS indicator assessment and prototype work.

The improvement-priority questions further showed what partners considered necessary to make EO-derived information more actionable. Across the three EWV improvement questions, temporal frequency received 24 selections, while spatial resolution and ground validation each received 18 selections (Figure 7). Uncertainty quantification followed with 12 selections. Data access and documentation, model integration, translation into indicators and transferability across case studies were selected less frequently. The results suggest that basic observation characteristics and validation remained the most immediate concerns: EO information first needs to resolve relevant processes at appropriate spatial and temporal scales and be supported by sufficient evidence of product quality before it can be reliably integrated into modelling and decision-support applications.

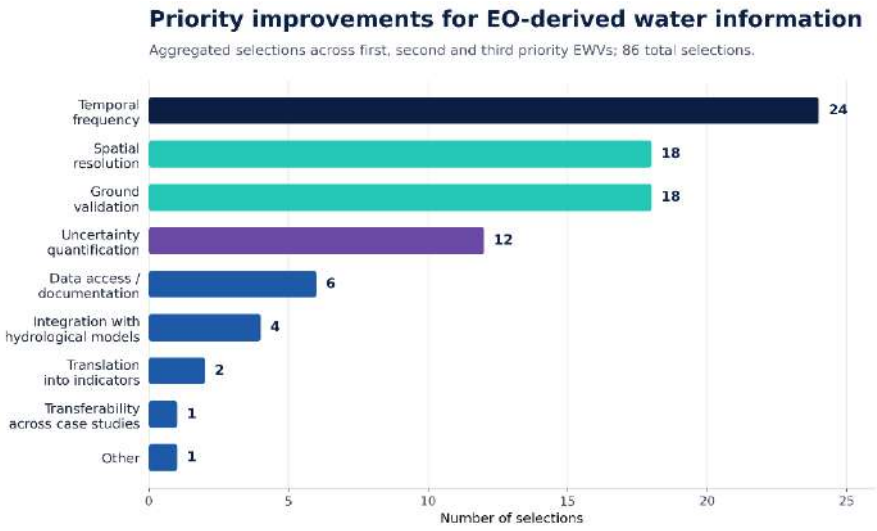

Figure 7: Expert survey results for prioritization of improvements for EO-derived water information.

Overall, the expert elicitation largely corroborated the technical findings presented in Sections 3.1 to 3.3. The recurring priorities were improved temporal and spatial sampling, stronger in situ support and validation, clearer uncertainty information, and better coverage of variables that remain difficult to observe directly, particularly human water use and key hydrological states and fluxes. The survey therefore provides an application-oriented perspective on which observation gaps were considered most consequential by partners developing and using the SOS-Water framework.

4 Bottlenecks for EO-supported basin-scale decision support

4.1 Limited in situ reference data and validation coverage

In situ observations remain a critical part of EO-supported water monitoring. They are required not only as an alternative source of information, but for calibration and validation of EO retrievals, evaluation of hydrological models, development of relationships between remotely sensed observables and water-system variables, and quantification of product uncertainty. SOS-Water repeatedly encountered situations in which the usefulness of spatially extensive EO information was constrained by the availability and representativeness of the underlying reference data.

This was particularly evident for the suspended particulate matter prototype. The EO retrieval produced good spatially distributed estimates, but reliable calibration and validation required dense station observations, and the relationships varied substantially between locations. Continuous sediment-flux estimation introduced a further dependency on discharge information and local sediment–discharge relationships. Similar dependencies occur for other EO-derived water variables, including surface water temperature, soil moisture, snow properties and discharge.

The bottleneck is therefore not simply that “more in situ data would be useful”. Sparse or unevenly distributed reference observations can determine where an EO algorithm can be confidently applied and where its performance remains uncertain. This is especially problematic when the intended value of EO is to improve information in poorly monitored regions.

4.2 Validation strategies and operational generalization

A separate issue concerns how validation is designed. For operational products intended to be applied across large regions, validation should demonstrate that the method generalizes beyond the specific locations, scenes and environmental conditions used during development. This is often not achieved by conventional random train–test splitting (Werther et al., 2025).

Spatial EO datasets commonly contain very strong autocorrelation. Pixels from the same lake, river reach, satellite scene or catchment are therefore not statistically independent samples. Random pixel-wise cross-validation can place highly similar observations in both training and test sets and consequently produce overly optimistic accuracy estimates. Such validation may quantify performance for additional pixels under already represented conditions, but provides little evidence that the method will perform similarly at an unseen lake, catchment or region. This problem is well established for spatial predictive models (Ploton et al., 2020; Roberts et al., 2017).

The relevant validation strategy should instead reflect the intended operational inference task. For the SOS-Water lake and river ice prototype, for example, the objective was to apply the classification methodology to lakes across the European Alps. A strict leave-one-lake-out cross-validation was therefore used: all observations from the evaluation lake were excluded from model training. This provides a substantially more relevant estimate of operational transferability than randomly withholding individual pixels from lakes that are otherwise represented in the training set.

The same principle applies at other scales. Depending on the product, the appropriate independent unit may be a water body, river reach, catchment, geographical region, climatic regime or time period. Validation strategies should therefore be selected according to the product's intended deployment domain rather than according to which design produces the highest accuracy statistics.

This distinction becomes particularly important when products developed using observations from a limited number of sites are subsequently operationalized at continental or global scale. High in-distribution accuracy should not be interpreted as evidence of geographical or environmental transferability unless this has explicitly been tested.

4.3 Mismatch between EO products, models and SOS indicators

SOS-Water encountered three recurring forms of mismatch: between the EO-derived quantity and the internal state of the receiving model, between the spatial or temporal unit of the product and the unit at which the model operates, and between the observed variable and the quantity that should ultimately support the decision.

A related mismatch concerns whether the spatial and temporal characteristics of an EO product are appropriate for the process and modelling scale at which it is used. Nominal product resolution or revisit frequency does not necessarily correspond to the effective information available after cloud filtering, aggregation, quality screening or gaps in acquisition. This becomes increasingly important as basin-scale hydrological models move towards daily frequency and kilometre-scale or even finer resolution, while several operational EO products remain substantially coarser or provide observations at irregular intervals. Where product scale, sampling and model representation are not aligned, potentially useful EO information can be smoothed, missed or become difficult to integrate without additional downscaling, aggregation or temporal processing.

The SWE EO Prototype illustrate the first type of mismatch. The downscaled SWE dataset represented snow storage more realistically than the temperature- and precipitation-driven snow module of CWatM, yet replacing that module with it reduced discharge performance in the Melach catchment of the Upper Danube. Recalibration recovered performance to a KGE of 0.66 but did not reach that of the standard calibrated model. This demonstrates that a model calibrated around a particular representation of accumulation and melt absorbs part of the basin water balance into those parameters, so an externally derived snow state cannot simply be substituted for them. Using the dataset instead as an independent calibration target, constraining degree-day melt factors, accumulation thresholds and albedo decay against observed snow storage rather than against discharge alone, proved the more productive pathway because it reduces equifinality without requiring the model structure to match the observation.

The altimetry EOP illustrates the second type of mismatch. SWOT provides water surface elevation at both node and reach level, and the choice between them determined whether the observation was usable. Node-level series at approximately 200 m reproduced in situ water levels with correlations approaching or exceeding 0.9 in the Danube Delta and the Rhine after bias correction, whereas reach-level aggregates at approximately 10 km performed consistently worse and became negatively

correlated with observations in the urbanised Linz reach. Aggregating to the reach scale removes the spatial detail a routing scheme requires, and averages together sections whose retrieval quality differs. Integration further required vertical datum harmonisation and quality filtering that the product does not carry out for the user. There is also an issue with the variable itself: water surface elevation was directly usable for benchmarking, whereas satellite-derived discharge (at the time of analysis) remained dependent on hydraulic assumptions and prior information and was not sufficiently mature for model integration.

The crop water productivity EOP illustrates the third mismatch. The Júcar hydro-economic model requires agricultural production and its response to irrigation deficit, and derives these by default from the FAO-66 yield-response approach applied to maximum production under full irrigation. Net biomass water productivity, expressed in kilograms of dry matter per cubic metre, is a different quantity: it describes total biomass rather than marketable yield, and converting between the two requires crop-specific harvest indices and local agronomic information.

These experiences indicate that a product intended for modelling and indicator workflows should state the quantity it represents in terms that map onto a model state, flux or forcing variable; should preserve the spatial and temporal unit at which the process is represented, or provide the disaggregated information alongside any aggregate; and should carry uncertainty at that same unit, so that the observation can be combined with the model estimate in proportion to the confidence in each, rather than simply replacing it. Where these conditions are not met, the consequence is not that EO is unusable, but that its role shifts from direct input to independent constraint, which is valuable but should be taken into account by the user.

4.4 Operational product stewardship and user-centred service design

Scientific accuracy alone does not make an EO product operational. Long-term use also depends on predictable access, transparent versioning, timely documentation and effective communication between product providers and the wider user community. These aspects become particularly important when products are incorporated into automated modelling and decision-support workflows.

Experience with operational EO datasets used in SOS-Water showed that substantial product changes may occur without sufficiently detailed or visible communication to external users. Where comprehensive version changelogs are unavailable, users may be unable to determine whether changes in a derived time series originate from environmental change or from modifications to algorithms, input data or processing chains. Documentation and best-use guidance may also lag behind product releases, reducing reproducibility and making migration between versions unnecessarily difficult.

Access architecture can create an equally important bottleneck. A dataset may technically be open while remaining operationally inaccessible if users must retrieve very large global files to analyse a small number of water bodies or a limited geographical region. For large, regularly updated products, efficient programmatic access and server-side spatial and temporal subsetting are therefore not

optional conveniences but important components of usability. Failure of an existing API or endpoint can disrupt downstream workflows even if the underlying files remain available.

A further weakness is that communication and feedback channels can be concentrated around the product-development consortium or directly funded users. An operational service should instead provide mechanisms through which the wider user community can receive release information, report problems and contribute feedback throughout the product lifecycle. Without such mechanisms, product teams may have limited visibility of how changes affect external operational workflows.

The bottleneck is therefore broader than data access alone. It concerns product stewardship: the continued management of versions, documentation, access infrastructure, known issues, communication and user feedback after a product has moved from research development towards operational service provision.

4.5 Implications for operational basin-scale decision support

Taken together, the bottlenecks identified above show that the technical availability of an EO-derived variable is not sufficient for operational basin-scale use. Its value depends on whether suitable reference data exist to establish confidence, whether validation demonstrates performance under the conditions in which the product will be applied, whether the observed quantity and its spatial and temporal scale are compatible with the receiving model or indicator framework, and whether the product can be accessed and maintained reliably over time. Limitations in any of these areas can substantially reduce the usefulness of otherwise scientifically valuable EO information.

For SOS assessment and decision support, EO products can therefore play different roles depending on their maturity and compatibility with the intended application. Some may be suitable as direct model inputs or indicator components, while others are more appropriately used for calibration, benchmarking, independent constraint or complementary spatial information. These roles should be stated explicitly, together with the relevant uncertainty, scale limitations and dependencies on in situ observations, models or auxiliary information.

Broader service-level issues such as fragmentation, interoperability and distributed access remain equally important, as highlighted by Water-ForCE. However, these should be distinguished from the fitness of the underlying products themselves. Better coordination between services, portals and formats cannot compensate for products that are insufficiently validated, poorly matched to the intended process scale or difficult to interpret in a modelling or decision context. Conversely, scientifically strong products can remain difficult to use operationally when they are fragmented across infrastructures or lack consistent access and metadata. Future water service development therefore needs to address both levels simultaneously: the quality and fitness-for-use of individual products, and the service architecture through which they are combined and delivered.

5 Actionable technical recommendations

The preceding chapters identified a range of observation gaps and practical bottlenecks encountered when EO-derived information is used for basin-scale modelling, Safe Operating Space assessment and decision support. These findings emerged from the broader SOS-Water EO data and gap assessment, the development and integration of EO prototypes, the SOS indicator framework, internal expert feedback and comparison with the strategic recommendations of Water-ForCE.

This chapter translates these findings into actionable technical recommendations for future EO-based water products and services, with a primary focus on Copernicus. The recommendations are organized into three complementary areas. First, an operational readiness framework is proposed to define the requirements that individual EO water products should meet to be fit for their intended use. We think that every operational product should comply with these to not be considered experimental. Second, priority improvements are identified for water-related information products and observation capabilities that remain limited, insufficiently mature or poorly matched to basin scale water resource applications. Third, these findings are synthesized into a set of priority areas for the future development of Copernicus water services.

The recommendations are not intended as universal specifications for every EO product. Requirements will differ depending on the water variable or proxy, spatial and temporal characteristics of the relevant process, and the intended monitoring, modelling or decision-support application. The central principle is that product development, validation, operational provision and maintenance should be aligned with the intended water-resource use case, and that remaining limitations and dependencies on in situ observations, models or other information sources should be made explicit.

5.1 Operational readiness framework for EO-based water products

Experience in SOS-Water showed that product availability or high reported retrieval accuracy alone does not determine whether an EO product is useful for water-resource assessment. A scientifically sound product may still have limited operational value if its spatial or temporal characteristics do not resolve the relevant process, if validation does not demonstrate transferability to the intended application domain, if the data cannot be accessed efficiently, or if changes to an operational product are poorly documented and communicated.

Figure 8 therefore proposes an operational readiness framework for EO-based water products and services. The framework is intended as a practical screening approach rather than a formal certification scheme. It evaluates product readiness across five connected dimensions: information relevance, observation scale and sampling, validation and generalization, operational usability, and long-term product stewardship. Rich reference data, uncertainty information, documentation and user feedback are cross-cutting requirements throughout the product lifecycle.

The final assessment is deliberately framed as “fit for intended use” rather than as a universal judgement of product quality. A product may be well suited to one application while being inappropriate for another. Readiness should therefore be demonstrated relative to the use that is

claimed for the product, and important limitations should remain visible to downstream users. Although the stated requirements seem to be standard considerations often discussed in relation to data products and the FAIR principles, we found that many water-related EO products currently in operation and in widespread use still do not fulfil many of these requirements.

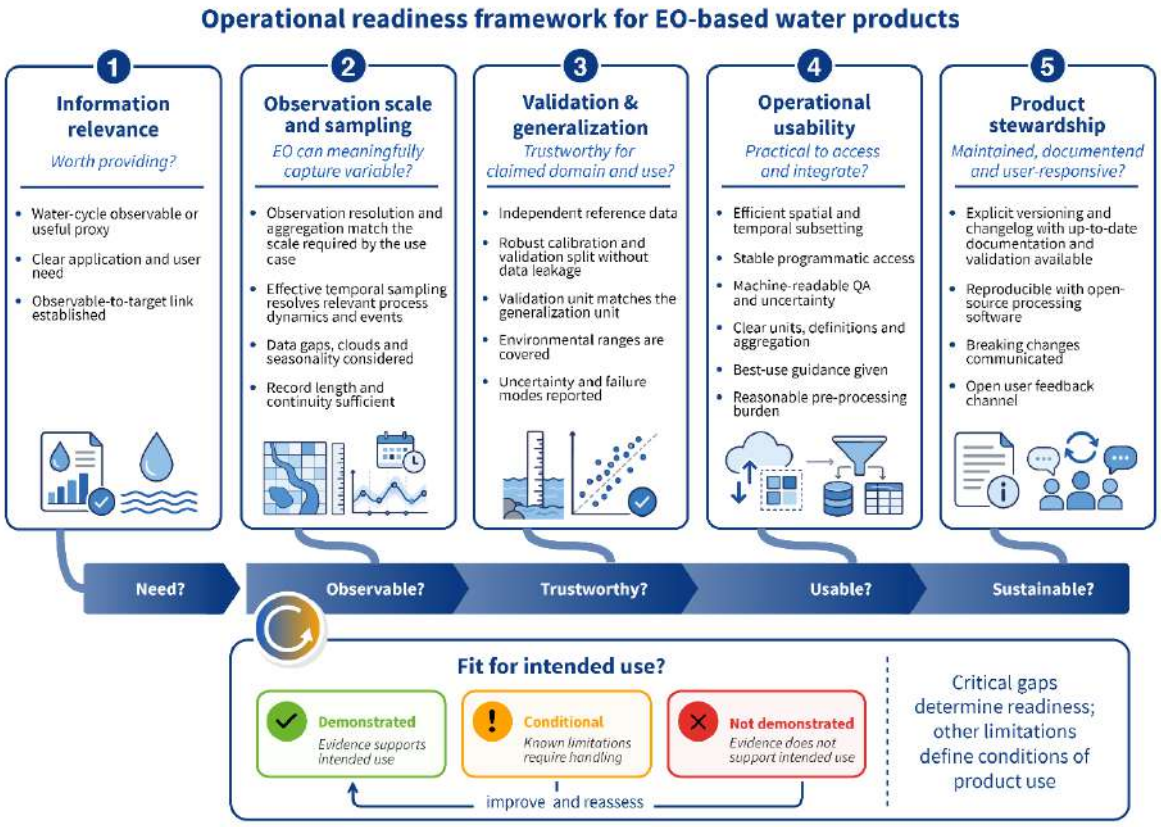

Figure 8: Operational readiness assessment framework for EO-based water.

5.1.1 Information relevance

Product development should start from a clearly defined water resource information need, rather than from the availability of a particular satellite observable. The product may represent a water cycle variable directly or provide a useful proxy, but the relationship between the EO observable and the quantity ultimately required for monitoring, modelling, indicator assessment or decision support should be explicit.

This distinction is particularly important where several processing or modelling steps separate the satellite measurement from the decision-relevant quantity. For example, water-surface elevation can provide valuable information on river dynamics without being equivalent to discharge, and evapotranspiration can constrain consumptive water use without directly representing abstraction or allocation. Product documentation should therefore clearly state what the product measures, what it can reasonably be used to infer, and where additional information is required.

5.1.2 Observation scale and sampling fitness

Product characteristics should be evaluated relative to the scales and dynamics of the process or event being monitored. Spatial resolution and temporal sampling are often the most important dimensions, but other characteristics can be equally relevant depending on the variable. Examples include sensing depth for soil moisture, or the spatial and temporal aggregation applied during product generation.

For spatially heterogeneous water systems, the observation scale needs to resolve the relevant entity or process without excessive aggregation or mixed-pixel effects. Temporal sampling should similarly reflect the relevant timescales of floods, sediment pulses, algal blooms, snowmelt, freeze-up and break-up, irrigation dynamics or other observed processes. Where relevant, the vertical or depth sensitivity of the observation should correspond to the quantity required by the application, for example surface versus root-zone soil moisture.

Products should report the effective sampling frequency and coverage of valid observations, not only the nominal revisit or production frequency. Cloud masking, quality filtering, retrieval failures and seasonal limitations can reduce a nominally daily product to much sparser usable coverage. Coverage statistics and data-availability metrics should therefore be provided with the product so users do not have to derive these themselves before assessing suitability.

5.1.3 Validation and generalization

Validation strategies should reproduce the intended operational inference task. In spatial EO applications, randomized k-fold cross-validation is often used for model validation. However, randomized pixel-level validation can substantially overestimate predictive performance when neighbouring pixels, or observations from the same water body, satellite scene, or catchment, occur in both training and evaluation datasets. Even without conventional data leakage, spatial and temporal autocorrelation can create strong dependence between training and evaluation samples, producing a leakage-like effect in which evaluation data are much more similar to the training data than genuinely unseen operational observations would be. Validation scores may therefore substantially overestimate performance on new water bodies, scenes, regions, or time periods.

The independent validation unit should therefore correspond to the scale at which the product is expected to generalize. Products intended for application to previously unseen waterbodies, basins or regions should demonstrate their main performance on appropriately independent hold-out units rather than relying primarily on randomized pixel-level validation. Claims of basin-, regional-, or continental-scale applicability require correspondingly independent evaluation. Validation should also cover the environmental range relevant to the product, including, where appropriate, different trophic states, optical water types, turbidity ranges, hydrological regimes, climatic conditions, or elevation zones.

A useful guiding principle is therefore: the validation unit should match the intended generalization unit. High in-distribution accuracy should not be presented as the primary evidence of operational performance when the intended use requires transfer to independent spatial, temporal, or environmental conditions. Suitable reference observations, genuine separation of model-

development and evaluation data, uncertainty estimates, and documented failure conditions are therefore integral parts of operational product validation.

5.1.4 Operational usability

Operational accessibility should be assessed against realistic user workflows, rather than only by whether the data can technically be accessed. Users should be able to retrieve the spatial and temporal subset required for their application without transferring or processing disproportionate amounts of unrelated data.

Large operational products should therefore provide stable programmatic access and efficient spatial and temporal subsetting. Quality flags, uncertainty information, masks and metadata should be machine-readable, while variable definitions, units and temporal or spatial aggregation should be unambiguous. Where particular filtering thresholds or processing steps are necessary for reliable use, these should be provided as explicit best-use guidance.

The processing burden required to integrate a product into modelling or indicator workflows is also part of usability. Products intended for widespread operational uptake should minimize unnecessary specialist pre-processing and make analysis-ready information available where technically feasible.

5.1.5 Product stewardship

Operational products require sustained product stewardship after their initial scientific development. Users need to know which processing version they are using, what has changed between releases and whether changes may affect established analyses or automated workflows.

Each major product release should therefore be accompanied by detailed version information and a public changelog covering relevant modifications to algorithms, input datasets, masks, calibration, quality control, file structures and access mechanisms. Documentation and best-use guidance, including instructions on how to interpret and apply quality information, should be released together with the product rather than substantially later. To ensure reproducibility, product releases should, whenever possible, be aligned with versioned open-source software releases.

Long-term stewardship should also ensure continuity across products, sensors, and processing versions. Where products are used for trend analysis, model benchmarking or other long-term applications, transitions between sensors or algorithms should be harmonized where possible and resulting discontinuities clearly documented, so that changes in the product record are not mistaken for changes in the observed system.

Users should also be informed proactively about new versions and breaking changes through open communication channels accessible beyond the immediate development consortium. Stable programmatic access, appropriate transition periods between major versions and public mechanisms for reporting issues and providing feedback should be considered part of operational service provision. Validation should likewise be revisited when the product expands to new sensors, regions or environmental conditions. Together, these five dimensions provide a first level of recommendations concerned with how operational EO water products should be developed and maintained. The

following sections address the complementary question of which water-information products need to be improved or developed further, and how these capabilities can be integrated into a more coherent Copernicus water-information framework.

5.2 Priority improvements to existing EO water products

Beyond the general operational-readiness requirements outlined above, SOS-Water identified several areas where existing EO-based water products could be improved to better support basin-scale modelling, monitoring and decision support. These needs concern variables for which operational products already exist, but where limitations in spatial or temporal resolution, geographical coverage, continuity, uncertainty characterization or the translation into management-relevant quantities still constrain their use. The priorities listed below are not intended as an exhaustive product review, but reflect recurring limitations identified through the SOS-Water data assessment, prototype development, model integration and expert feedback.

- **Expand and strengthen operational inland water quality products.** Water quality remains comparatively underrepresented in the Copernicus water portfolio relative to water quantity information. Further development should therefore prioritise a broader and more mature set of inland water quality products, particularly for variables that are relevant to ecosystem status, sediment dynamics and basin management but are still only partially covered by current operational services.

- **Prioritize long-term harmonized records across sensors and missions.** Many Copernicus water products are closely tied to individual sensors or mission periods, which can limit continuity once a sensor changes or a processing line is discontinued. For climate, trend and basin-scale applications, long and internally consistent records are often more valuable than isolated mission-specific products. Future product development should therefore place greater emphasis on cross-sensor harmonisation, continuity between missions and stable long-term archives, following approaches already established in programmes such as ESA CCI Lakes.

- **Preserve the highest useful temporal resolution where possible.** Several Copernicus products are distributed as multi-day aggregates, for example 10-day composites, even when observations are available at a finer temporal frequency. Aggregation can reduce data volume and suppress noise, but it can also obscure short-lived events and rapid dynamics. For applications such as algal-bloom detection, thermal front tracking, flood evolution or freeze-up and break-up, access to the underlying higher-frequency observations can be essential. Operational services should therefore provide native or near-native temporal information alongside aggregated products where technically feasible.

- **Snow water equivalent in mountainous terrain.** The operational Copernicus SWE products are derived from passive-microwave retrievals that are provided only for non-mountainous regions, which excludes precisely the areas where snow storage dominates basin water

availability. Together with a 5 km grid, this leaves snow-dominated headwaters without an operational SWE product. A mountain-capable SWE product at kilometre scale, combining passive microwave, optical snow cover, reanalysis and in situ observations with terrain-aware retrieval, is a high priority for European basin hydrology.

- **From evapotranspiration to water productivity.** The new CLMS actual evapotranspiration products at 300 m globally are a substantial advance, but evapotranspiration alone does not answer how efficiently consumed water is converted into production. Copernicus should publish a biomass or net primary productivity term on the same grid and calendar, together with the evaporation–transpiration partitioning, so that water productivity and SDG 6.4.1 reporting can be derived consistently rather than rebuilt by each user.

- **Reservoir and lake storage volume.** Copernicus provides water body extent and, through related services, water level, but no operational product converting these into stored volume. Reservoir storage is a direct SOS indicator in several case studies and a first-order control on managed-basin behaviour. Combining extent, level and hypsometry into a maintained storage product would close a gap that users currently fill with ad hoc local processing.

- **Root-zone rather than surface soil moisture.** Operational soil moisture products describe the near-surface layer, whereas models and irrigation applications need root-zone storage. Root-zone products exist as indices but lack documented depth weighting, validation against profile measurements and per-pixel uncertainty. Establishing these would make them usable for assimilation rather than only for qualitative interpretation.

5.3 Priority areas for future Copernicus water-service development

Some of the gaps identified in SOS-Water cannot be addressed through incremental improvements to individual products alone. They require broader development of the Copernicus water-information framework, including new observation capabilities, better coordination across the water cycle, stronger integration of EO with models and in situ information, and improved provision of decision-relevant quantities that cannot be observed directly from space. The priorities below therefore synthesize the application-level experience of SOS-Water with the broader service-level perspective of Water-ForCE and highlight areas where coordinated development could substantially strengthen the role of Copernicus in operational basin-scale water assessment and management.

- **Develop dedicated EO products for river monitoring**. Rivers remain underrepresented in the current Copernicus water-product portfolio, despite their central role as freshwater habitats and as transport corridors for sediment, heat, nutrients and pollutants. They are also strongly affected by anthropogenic pressures such as dams, flow regulation, land-use change and pollution. Future Copernicus development should therefore include dedicated river-focused products, for example for turbidity and suspended sediment, using retrieval, calibration and

validation approaches designed specifically for river environments and supported by representative riverine in situ observations.

- **Water-cycle consistency across services.** Precipitation, evapotranspiration, snow, soil moisture, storage change and surface water products are developed independently, on different grids, calendars and uncertainty conventions, and do not close a basin water balance when combined. For basin-scale modelling, a coordinated set of water-cycle products delivered on a common grid and calendar with harmonised uncertainty would be more valuable than incremental accuracy improvements in individual products. This is a concrete expression of the Water-ForCE virtual-service and core-service scenarios.

- **Model- and assimilation-ready provision.** Copernicus water products should be published in a form that allows them to enter model workflows directly: per-pixel uncertainty, quality flags, native-resolution data alongside any aggregate, stable APIs, and explicit guidance on what the product measures and how it relates to common model state variables.

- **Human water use as a sustained information layer.** Water demand, abstraction and allocation were the most frequently prioritised information need in the internal elicitation and remain the largest gap in the operational portfolio. It is recommended for Copernicus to support a sustained layer combining EO-derived irrigated area, crop type and consumptive use with reported abstraction and allocation data, accepting that such a product is necessarily a combination of observation, modelling and administrative information.

- **Transferability beyond Europe and discoverability through GEOSS.** Copernicus water products are widely applied outside Europe, including in the Mekong case study and in development-finance applications, where suitable reference data for independent validation may be limited. For greater outreach and impact, global transferability should be treated as a design requirement rather than a by-product. Products intended for global use should therefore be validated across representative environmental and climatic conditions, with regional limitations and uncertainty made explicit. At the same time, consistent metadata and standards-based publication through frameworks such as GEOSS can improve international discoverability and facilitate access to Copernicus products alongside complementary EO, in situ and modelling datasets.

- **Sustain and advance satellite gravimetry for water resource monitoring.** GRACE and GRACE-FO provide an independent and globally consistent observation of terrestrial water-storage change, including sensitivity to subsurface storage components that are difficult to observe with other EO techniques. SOS-Water hydrologists identified this information as particularly valuable, but the coarse spatial resolution of current products, typically several hundred kilometres, limits their use at the scale of individual river basins, aquifers and water-management regions.

Future Copernicus water services should therefore recognize continuity and advancement of satellite gravimetry as a strategic observation requirement. This includes support for next-generation missions with improved spatial and temporal resolution, as well as the development of downstream products and assimilation approaches that make gravimetry easier to use in hydrological applications. ESA's Next Generation Gravity Mission (NGGM), within the planned ESA–NASA MAGIC constellation, provides an important pathway for continuing the GRACE/GRACE-FO record while increasing its value for groundwater, drought, terrestrial water-storage and basin water-balance monitoring

References

Brechbühler, M. (2025). *SOS-Water D3.1 Data inventory*. Zenodo. https://doi.org/10.5281/zenodo.17475622

Brechbühler, M., Nguyen Trung, N., Rotaru, S., Simons, G., & Odermatt, D. (2023). *Data inventory and EO data needs for water resources monitoring* (Number D3.1). https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5f9defeca&appId=PPGMS

Brechbühler, M., Odermatt, D., Portugués, J., Nolet, C., Contreras, S., Fernández-Rodríguez, A., & Simons, G. (2026). *Improved EO application prototypes* (Number D3.2). https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5283bcfcd&appId=PPGMS

Ellis, E. A., Allen, G. H., Riggs, R. M., Gao, H., Li, Y., & Carey, C. C. (2024). Bridging the divide between inland water quantity and quality with satellite remote sensing: An interdisciplinary review. *WIREs Water*, *11*(4). https://doi.org/10.1002/wat2.1725

European Union Copernicus Land Monitoring Service. (2025). *Aggregated Water and Ice Cover S1&S2 2016-present (vector), Europe, NRT*. European Environment Agency. https://doi.org/10.2909/5752e8b5-ecda-4013-8eb9-e27f8515b87e

Falkenmark, M., & Wang-Erlandsson, L. (2021). A water-function-based framework for understanding and governing water resilience in the Anthropocene. *One Earth*, *4*(2), 213–225. https://doi.org/10.1016/j.oneear.2021.01.009

Foster, T., Mieno, T., & Brozović, N. (2020). Satellite-Based Monitoring of Irrigation Water Use: Assessing Measurement Errors and Their Implications for Agricultural Water Management Policy. *Water Resources Research*, *56*(11). https://doi.org/10.1029/2020WR028378

García-García, A., Stradiotti, P., Di Paolo, F., Filippucci, P., Fischer, M., Orság, M., Brocca, L., Peng, J., Dorigo, W., Gruber, A., Droppers, B., Wanders, N., Haag, A., Weerts, A., Modiri, E., Rakovec, O., Francés, F., Dall'Amico, M., Anderson, M., … Samaniego, L. (2026). Intercomparison of Earth Observation products for hyper-resolution hydrological modelling over Europe. *Remote Sensing of Environment*, *333*, 115131. https://doi.org/10.1016/j.rse.2025.115131

Kutser, T., Spyrakos, E., WIlson, H., Tyler, A., Simis, S., Van Duibenbode, L., Reusen, I., Laas, A., Ioana, P., van Griensven, A., Escorihuela, M. J., Giardino, C., Bresciani, M., Pesquer Mayos, L., Ogashawara, I., Bassa, L., Thant, S., Walker, P., de Moortel, I., … Cillero Castro, C. (2024). *A Roadmap for Copernicus water services*. Zenodo. https://doi.org/10.5281/zenodo.10847654

Lubczynski, M. W., Leblanc, M., & Batelaan, O. (2024). Remote sensing and hydrogeophysics give a new impetus to integrated hydrological models: A review. *Journal of Hydrology*, *633*, 130901. https://doi.org/https://doi.org/10.1016/j.jhydrol.2024.130901

McCabe, M. F., Rodell, M., Alsdorf, D. E., Miralles, D. G., Uijlenhoet, R., Wagner, W., Lucieer, A., Houborg, R., Verhoest, N. E. C., Franz, T. E., Shi, J., Gao, H., & Wood, E. F. (2017). The future of Earth observation in hydrology. *Hydrology and Earth System Sciences*, *21*(7), 3879–3914. https://doi.org/10.5194/hess-21-3879-2017

Odermatt, D., Gitelson, A., Brando, V. E., & Schaepman, M. (2012). Review of constituent retrieval in optically deep and complex waters from satellite imagery. *Remote Sensing of Environment*, *118*, 116–126. https://doi.org/10.1016/j.rse.2011.11.013

Palmer, S. C. J., Kutser, T., & Hunter, P. D. (2015). Remote sensing of inland waters: Challenges, progress and future directions. *Remote Sensing of Environment*, *157*, 1–8. https://doi.org/10.1016/j.rse.2014.09.021

Ploton, P., Mortier, F., Réjou-Méchain, M., Barbier, N., Picard, N., Rossi, V., Dormann, C., Cornu, G., Viennois, G., Bayol, N., Lyapustin, A., Gourlet-Fleury, S., & Pélissier, R. (2020). Spatial validation reveals poor predictive performance of large-scale ecological mapping models. *Nature Communications*, *11*(1), 4540. https://doi.org/10.1038/s41467-020-18321-y

Roberts, D. R., Bahn, V., Ciuti, S., Boyce, M. S., Elith, J., Guillera-Arroita, G., Hauenstein, S., Lahoz-Monfort, J. J., Schröder, B., Thuiller, W., Warton, D. I., Wintle, B. A., Hartig, F., & Dormann, C. F. (2017). Cross-validation strategies for data with temporal, spatial, hierarchical, or phylogenetic structure. *Ecography*, *40*(8), 913–929. https://doi.org/10.1111/ecog.02881

Simons, G., Contreras, S., Schults, T., Nolet, C., Odermatt, D., & Brechbühler, M. (2025). *Integration of novel EO products into basin-scale water resources modelling* (Number D3.3). https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5283be321&appId=PPGMS

Tyler, A. N., Hunter, P. D., Spyrakos, E., Groom, S., Constantinescu, A. M., & Kitchen, J. (2016). Developments in Earth observation for the assessment and monitoring of inland, transitional, coastal and shelf-sea waters. *Science of The Total Environment*, *572*, 1307–1321. https://doi.org/10.1016/j.scitotenv.2016.01.020

van Jaarsveld, B., Wanders, N., Sutanudjaja, E. H., Hoch, J., Droppers, B., Janzing, J., van Beek, R. L. P. H., & Bierkens, M. F. P. (2025). A first attempt to model global hydrology at hyper-resolution. *Earth System Dynamics*, *16*(1), 29–54. https://doi.org/10.5194/esd-16-29-2025

Werther, M., Burggraaff, O., Gurlin, D., Saranathan, A. M., Balasubramanian, S. V, Giardino, C., Braga, F., Bresciani, M., Pellegrino, A., Pinardi, M., Simis, S. G. H., Lehmann, M. K., Kangro, K., Alikas, K., Ficek, D., & Odermatt, D. (2025). On the generalization ability of probabilistic neural networks for hyperspectral remote sensing of absorption properties across optically complex waters. *Remote Sensing of Environment*, *328*, 114820. https://doi.org/https://doi.org/10.1016/j.rse.2025.114820

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