RETOUCH NEXUS

REsilienT water gOvernance Under climate CHange within the WEFE NEXUS

Deliverable D1.4

Available data, data gaps and their implications

Henao, Juan P. (TUM); Sala, Pietro (TUM); Vrachioli, Maria (TUM); Villalba, Roberto (TUM).

With contributions from: van der Grijp, Nicolien (VUA); Aufdembrinke, Lilly (adelphi); Rubio, Adria (UPV); Lazorcakova, Ema (SUA); Rajcaniova, Miroslava (SUA)

Date (28/06/2024)

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

RETOUCH NEXUS

RETOUCH NEXUS Partners

Technical University of Munich - TUM (Germany) - Maria Vrachioli, Johannes Sauer, Markus Disse, Roberto Villalba, Pietro Sala, Juan Pablo Henao Henao, Jingshui Huang & Nicole Tatjana Scherer

Universitat Politècnica de València - UPV (Spain) - Manuel Pulido-Velazquez, Hector Macian-Sorribes, Adria Rubio-Martin & Eulalia Gomez Martin

Vrije Universiteit Amsterdam - VUA (Netherlands) - Erik Ansink, Nicolien van der Grijp, & Leon Bremer

adelphi research gemeinnutzige - adelphi (Germany) - Annika Krammer, Elsa Semmling, Binayak Das & Lilly Aufdembrinke.

Slovak University of Agriculture - SUA (Slovakia) - Jan Pokrivcak, Ema Lazorcakova & Miroslava Rajcaniova

Euroquality - EQY (France) - Barthélémy Maillard, Clémence Gracia & Solène Fovelle

Vlaamse Instelling voor Technologisch Onderzoek - VITO (Belgium) - Katrien Van Hooydonk, Lilian Tavernier, Steven Broekx & Wim Schiettecatte

De Watergroep - DWG (Belgium) - Pauline Ottoy, Charlotte Jacobs & Ian Montauban Van Swijndregt

Energy and Water Agency - EWA (Malta) - Manuel Sapiano, Nicholas Ellul, Aaron Cutajar, Nadia Gatt Gafa & Marco Graziani

Hoogheemraadschap Hollands Noorderkwartier - HHNK (Netherlands) - Floor van Schie, Ronald Koolen & Marja Korting

Greening the Islands - GtI (Italy) - Gianni Chianetta, Emilio Gabrielli, Fransesco Luise, Mattia Monaco, Andrea Morabito, Sabrina Pentecoste, Jean Karl Micallef-Grimaud, Graziana Salvati

Regierung Oberfranken - RegOb (associated) (Germany) - Andrea Kuenzl

Ministry of Agriculture and Rural Development - MARD (associated) (Slovakia) - Martin Kovac

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

DELIVERABLE 1.4

Project Acronym	RETOUCH NEXUS
Project Title	REsilienT water gOvernance Under climate CHange within the WEFE NEXUS
Project Coordinator	Maria Vrachioli
Project Duration	01.01.2023 – 31.12.2026

Nature of the deliverable		
R	Document, report (excluding the periodic and final reports)	X
DEM	Demonstrator, pilot, prototype, plan designs	
DEC	Websites, patents filing, press & media actions, videos, etc.	
OTHER	Software, technical diagram, etc.	

Dissemination Level		
PU	Public, fully open, e.g. web	X
CO	Confidential, restricted under conditions set out in Model Grant Agreement	
CI	Classified, information as referred to in Commission Decision 2001/844/EC	

Deliverable No.	D1.4 Available data, data gaps and their implications for the quantification of the water governance indicators
Dissemination level [1]	PU
Work Package	WP 1 – Assess and monitor sustainable water governance
Task	T 1.4 - Data and monitoring framework basis
Lead beneficiary	TUM
Contributing beneficiary(ies)	UPV, VUA, SUA, adelphi, EWA, GtI, MARD
Due date of deliverable	30 June 2024
Actual submission date	28 June 2024

Quality procedure			
Date	Version	Reviewers	Comments
11 June 2024	V1.0	Leon Bremer, Adria Rubio-Martin, Aaron Cutajar, Binayak Das	
28 June 2024	V2.0		

Acknowledgements

This report is part of the deliverables from the project "RETOUCH NEXUS" which has received funding from the European Union's Horizon Europe research and innovation program under grant agreement N° 101086522. More information on the project can be found at www.retouch-nexus.eu

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Executive summary

This document reports on Task 1.4 of the RETOUCH NEXUS Project: *Data and monitoring framework basis*. We build on Task 1.3 of the same project (*Set of existing and new indicators for monitoring water governance*) reported in D1.3. We provide a refined list of indicators, a monitoring framework, and for each indicator we highlight publicly available data sources and assessment strategies. The proposed monitoring framework builds on the OECD water governance indicator framework and considers additional indicators to allow assessing policy outcomes and to understand the interactions between the Water, Energy, Food and Ecosystems (WEFE) Nexus. The indicators within our framework support decisions related to water allocation, the distribution of water-related benefits, and the formal and informal institutions involved in the decision-making processes regarding water management.

For the assessment of indicators within our monitoring framework, we propose a step-by-step procedure. In the first step, it is necessary to select the most relevant indicators for the given context. This is done for both the qualitative and quantitative indicators. Once this has been done, the subsequent steps vary depending on the type of indicator. We identify publicly available data sources for quantitative ones, and we describe how qualitative can be assessed. Whenever data is unavailable we explore alternative options.

We conclude by highlighting the lessons learned and the implications for the RETOUCH NEXUS project. In general, given the available data sources, water governance can be assessed at the national scale. The specificities of the smaller scales and the lack of publicly available data obstruct its assessment more locally. RETOUCH NEXUS will apply the indicators to the six case studies to gain direct experience on filling this gap.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

RETOUCH NEXUS

Contents

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

RETOUCH NEXUS

Abbreviations

ARRI	Aquifer Recharge Rate Index
EC	European Commission
EEA	European Environment Agency
ES	Ecosystem Services
ET	Evapotranspiration
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
MDWL	Matching Degree of Water Land Resources
SDG's	Sustainable Development Goals
SOC	Soil Organic Carbon
SRI	Standardized Runoff Index
WEFE	Water, Energy, Food, Ecosystems
WEI	Water Exploitation Index
WFD	Water Framework Directive
WISE	Water Information System for Europe
WSI	Water Stress Index
WTA	Withdrawals to Availability Ratio

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

List of Figures

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

List of Tables

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

1. Introduction

This document reports on Task 1.4 of the RETOUCH NEXUS Project: *Data and monitoring framework basis*. We build on Task 1.3 of the same project (*Set of existing and new indicators for monitoring water governance*) reported in D1.3. This report is intended for decision-makers, academics, and stakeholders who are involved in and affected by water governance practices within the EU. After piloting the framework across RETOUCH NEXUS case studies, we will elaborate on lessons learned to upscale the framework to a variety of scenarios (T 1.5).

The report is composed of multiple sections, as follows. The next section describes what a monitoring framework is in the context of water governance, building on the knowledge provided in D1.3. Section 3 describes available data sources (and data gaps) for assessing the proposed monitoring framework. We give particular emphasis to publicly available data from multiple sources and platforms. When data is unavailable, we highlight alternative options or a pathway for gathering relevant information. Section 4 concludes by highlighting the implications of data availability and describing the next steps the project will follow during the development of Work Package 1.

2. Data and Monitoring Framework basis

Identifying and assessing indicators is vital to support evidence-based monitoring performance, plan adjustments, and to improve resilience. A robust monitoring framework in water governance should include indicators to support decisions related to water allocation and the distribution of water-related benefits (Jacobson *et al.*, 2013). Furthermore, a water governance-monitoring framework should also consider the formal and informal institutions involved in the decision-making processes regarding water management (OECD, 2015). We consider these aspects to provide a water governance-monitoring framework that combines these two dimensions and allows for cross-sectoral water management. This section describes this monitoring framework and the indicators within.

Assessing the WEFE Nexus

The WEFE Nexus is "an approach that integrates management and governance *across sectors and scales […] which aims, among other things, at resource use efficiency and greater policy coherence. Given the increasing interconnectedness across sectors and in space and time, a reduction of negative economic, social and environmental externalities can increase overall resource use efficiency, provide additional benefits and secure the human rights*" (Hoff *et al.*, 2011, p. 7). One of the main goals of the RETOUCH NEXUS project is to mainstream this approach into a water governance monitoring framework. To do this, we use the indicators identified in T1.3 that aim at capturing fundamental aspects of water governance and the general WEFE NEXUS setting. Through their assessment, we make such aspects measurable, and thus comparable. As we will explain in the following subsections, assessment must be undertaken on a case-to-case basis, depending on the specific characteristics of each context.

Criteria for indicator selection

Following D1.3, we consider the following criteria for the selection of the indicators within the monitoring framework:

- Indicators should be relevant to the current policy and regulatory framework of the European Union (e.g., the Water Framework Directive, Floods Directive, Drinking Water Directive, Urban Wastewater Treatment Directive, Habitats Directive).

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

- Indicators should be relevant for the Sustainable Development Goals (SDGs).
- Indicators should span multiple time planning horizons (e.g., short-term, long-term).
- Indicators should be applicable to the multiple scales of the RETOUCH NEXUS case studies.[1]
- Indicators should allow setting or developing policy objectives.
- Indicators should address the multiple types of water (green water, blue water, grey water).
- Indicators should span the different pillars of the WEFE Nexus.

Monitoring

In this section, following D1.3, we propose a map for the selected indicators that allows assessing water governance over different spatial and temporal scales (Figure 1). We build on the literature by taking the OECD water governance indicator framework as a starting point and suggesting additional layers of indicators that allow monitoring water governance across multiple scales and sectors over time. We refer to this approach as a multi-level and cross-sectoral reasoning. Such an approach should complement existing monitoring frameworks to allow assessing not only governance set ups, but also their performance and implications. For this reason, we consider pure governance indicators, as well as indicators related to the multiple aspects of water management. This allows assessing the performance of governance systems and the impacts of specific policy interventions, over different scales. The assessment and use of these indicators should be a continuous process of the water governance monitoring cycle.

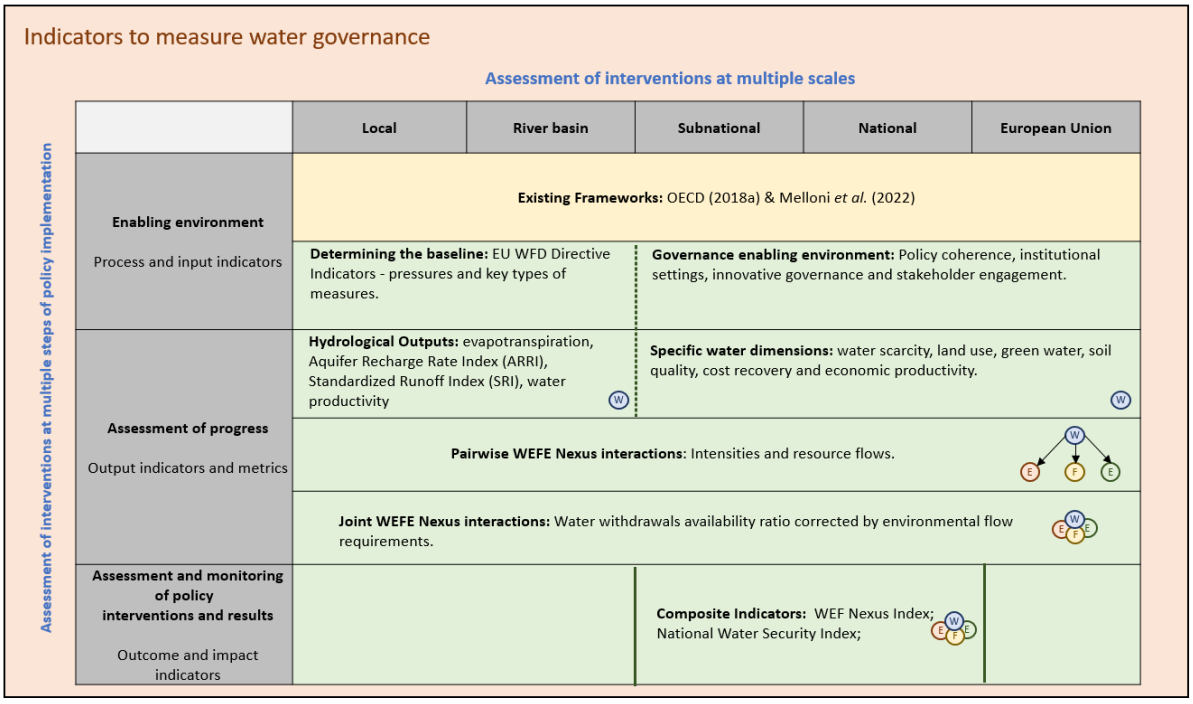


Figure 1. Map of RETOUCH NEXUS indicators for assessing water governance over different spatial and temporal scales (Research Perspective).

[1] Case studies | Retouch-Nexus

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

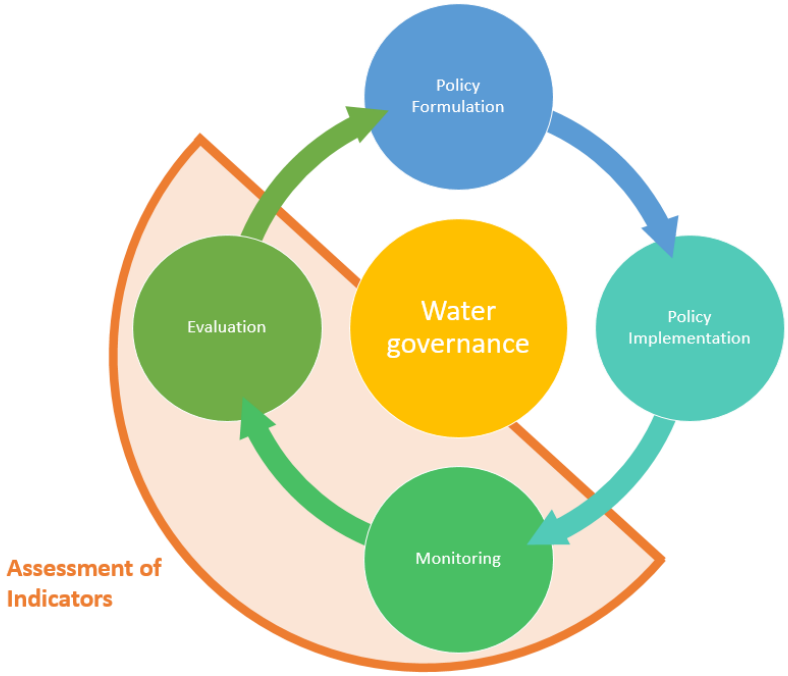


Figure 2. Assessment of indicators and water governance monitoring cycle.

Links with the OECD Water governance indicator framework

The OECD defines water governance as "the range of political, institutional and administrative rules, practices and processes (formal and informal) through which decisions are taken and implemented, stakeholders can articulate their interests and have their concerns considered, and decision-makers are held accountable for water management" (2015, p.5). OECD (2018a) provides some important implications of this definition: i) water governance is broader in scope than government. It is a participatory process that considers the needs and interests of all the relevant stakeholders (public and private sectors included). This means that there should be clarity on who needs water and for what purpose; ii) water governance is an iterative process. It goes beyond political, institutional and administrative rules to consider formal and informal decision-making processes; and iii) there should be accountability for water management decisions. In particular, there should be clarity on who does what and at which level. These implications suggest that implementing and assessing water governance arrangements is a highly complex mission (OECD, 2018a).

An important opportunity to further refine the OECD water governance indicator framework is to include additional types of indicators that assess performance on different levels. The main five types of indicators recognized in the academic literature are process, input, output, outcome and impact indicators. Jacobson et al. (2013) introduce this taxonomy to the context of water governance (see Table 1, below). In this sense, the different type of indicators flow across different levels of complexity (blue arrow) with process and input indicators being those easier to control all the way to impact indicators which are the result of multiple outcomes interacting together. The OECD indicator framework considers only process and input indicators. In the monitoring framework proposed in this document we consider also output, outcome and impact indicators.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Table 1. Types of indicators and different levels.

Type of Indicator	**Description**	**Scope of assessment**
Process	Process indicators measure actions and activities required to achieve a desired policy goal.	
Input	Input indicators measure the amount of resources needed to achieve a desired policy goal. Legislation and policy instruments are also considered 'inputs'.	
Output	Output indicators measure the existence, quality and quantity of products or services needed to achieve a desired policy goal. In this context products and services are the concrete and immediate result of an input or activity.	
Outcome	Outcome indicators measure the results that set the ground to deliver 'impacts'. Results are often consequences of the interaction of outputs and produce intermediate milestones needed to achieve the desired target policy goal.	
Impact	Impact indicators measure the progress in achieving ambitious policy-objective over the longer term. They are often political goals, for example, SDGs.	

Source: adapted from Jacobson *et al.* (2013).

Indicators – Summary and classification

In this section, we present the shortlist of indicators we selected with the help of experts' opinions, which should support decision-makers and other stakeholders exploring monitoring frameworks for water management, from a WEFE NEXUS perspective. The list provides a preliminary overview of dimensions that should be taken into account, in a general case study. These should be further refined according to the characteristics of the context under assessment, selecting the indicators that are relevant to it, and eventually integrating additional variables where necessary.

We divide our indicators into two categories: qualitative and quantitative. While considering the two groups differently, we recognize the need to include both types in our monitoring framework. On the one hand, qualitative indicators serve the purpose of understanding the surrounding environment (institutional and policy settings and stakeholder interactions). Their assessment relies on stakeholder feedback to capture all the relevant impressions and viewpoints. While these indicators are context dependent and their qualitative nature does not necessarily allow comparisons, we include them in similar fashion to the OECD water governance indicator framework. Furthermore, their inclusion is critical to understanding the enabling environment of a given context. Conversely, quantitative indicators describe long-term and short-term changes in the WEFE Nexus status and water use. These indicators allow to compare changes over time in a specific context and, in some cases, among

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

different scenarios. Table 2 and Table 3 list the selected indicators providing their name, classification, and unit of measurement. In section 3, they are described in detail.

Quantitative

Table 2. List of quantitative indicators.

ID	Group	Name	Unit
1.1	1	Hydromorphological alterations preventing the achievement of WFD objectives	Km^2, Km
1.2	1	Physical loss of habitats is preventing the achievement of objectives	Km^2, Km
1.3	1	Number of sites (per activity) preventing the achievement of objectives	Number of sites
1.4	1	Area required to be covered by measures to achieve WFD Objectives	Km^2, Km
1.5	1	Water bodies/river networks required to be restored to achieve objectives	Km^2, Km
1.6	1	Contaminated sites preventing the achievement of objectives	Number of sites
1.7	1	Discharges preventing the achievement of objectives	Number of sites
1.8	1	Contaminated sites to be remediated to achieve objectives	Number of sites
1.9	1	Drinking water protection zones required to achieve objectives	Number of sites
1.10	1	Surface water interceptors and treatment facilities required to achieve objectives	Number of sites
1.11	1	Waste disposal sites required to be upgraded or remediated to achieve objectives	Number of sites
1.12	1	Wastewater treatment works requiring to be constructed or upgraded to achieve objectives	Number of sites
1.13	1	Water pricing policy measures are required to achieve the objectives of WFD Article 9	Km^2, Km
1.14	1	Installations where upgrades or improvements are required to achieve objectives	Number of sites
1.15	1	Storm overflows required to be upgraded to achieve objectives	Number of sites
3.1	3	Evapotranspiration	mm d^{-1} ; mm/month; mm y^{-1}
3.2	3	Aquifer Recharge Rate Index (ARRI)	mm y^{-1}; $m^3 y^{-1}$
3.3	3	Standardized Runoff Index (SRI)	-
3.4	3	Water Productivity	Kg m^{-3}; € m^{-3}
4.1	4	Soil Organic Carbon (SOC)	% (at top X cm of soil)
4.2	4	Soil erosion rate	T ha^{-1} y^{-1}
4.3	4	Falkenmark or Water Stress Index (WSI)	$m^3ha^{-1}y^{-1}$; $m^3ha^{-1}m^{-1}$
4.4	4	Water Withdrawals to Availability ratio (WTA ratio) or Water Exploitation Index + (WEI+)	%
4.5	4	Matching Degree of Water Land Resources (MDWL)	m^3ha^{-1}
4.6	4	Water Retention Capacity of Soil	m^3ha^{-1}
4.7	4	Cost recovery of water services	%

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

ID	Group	Name	Unit
4.8	4	Water Economic Productivity	$m^3\$^{-1}$
4.9	4	Environmental Flow Requirements	m^3/Month
5.1	5	Cross-sectoral water flow quantities	m^3/Month
5.2	5	Cross-sectoral Water Use Intensities (Water Footprint)	m^3t^{-1} or m^3Wh^{-1} (Energy), m^3t^{-1} (Food)
6.1	6	WEFE WTA Ratio	%
7.1	7	WEF Nexus Index	-
7.2	7	National Water Security Index	-

Qualitative

Table 3. List of qualitative indicators

ID	Group	Name	Unit
2.1	2	Familiarity with a WEFE nexus or other integrated approach	0-5 (levels); 0-4 (consensus)
2.2	2	Supportive scientific infrastructure	0-5 (levels); 0-4 (consensus)
2.3	2	Facilitation of a multi-level approach	0-5 (levels); 0-4 (consensus)
2.4	2	Overarching and challenging policy paradigm	0-5 (levels); 0-4 (consensus)
2.5	2	Testing of innovative practices	0-5 (levels); 0-4 (consensus)
2.6	2	Exploration of new practical tools	0-5 (levels); 0-4 (consensus)
2.7	2	Stakeholder perception – relevance.	0-5 (levels); 0-4 (consensus)
2.8	2	Exchange platform for stakeholder feedback	Y/N; 0-3 (transparency)
2.9	2	Formalized mechanisms for public consultation	Y/N; 0-3 (implementation)
2.10	2	Conflicts of interest – management and disclosure	Y/N; 0-3 (conflict management); 0-3 (conflict disclosure)
2.11	2	Consultation of women and marginalised populations	Y/N; 0-4 (consultation)
2.12	2	Mechanisms to address identified water governance gaps	Y/N; 0-3 (implementation)
2.13	2	Availability of required translations	Y/N; 0-3 (degree of publishing/sharing)
2.14	2	Key performance indicators (KPIs)	Y/N; 0-3 (success)
2.15	2	Formal and informal stakeholder engagement mechanisms	Y/N; 0-3 (implementation)
2.16	2	Joint stakeholder process	0-3 (inclusion); 0-3 (consensus)
2.17	2	Problem definition sharing	0-3 (sharing); 0-3 (consensus)
2.18	2	Water allocation priorities	Y/N; 0-3 (consensus)

As described in **Error! Reference source not found.**, the proposed monitoring framework contains both quantitative and qualitative indicators. We propose a classification of seven groups representing key aspects of water governance and the WEFE NEXUS. Following **Error! Reference source not found.**,

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

we consider the following: WFD indicators, governance and enabling environment indicators, hydrological indexes, water dimensions, pairwise WEFE cross-sectoral interactions, joint WEFE NEXUS interactions, and composite indicators. Furthermore, our monitoring framework links to the SDG as illustrated in

Figure 3. In general, SDGs 2, 6, 7 and 15 are the most represented as they deal with food, water, energy and ecosystems, respectively. Nevertheless, we also highlight the contribution to other relevant SDGs.

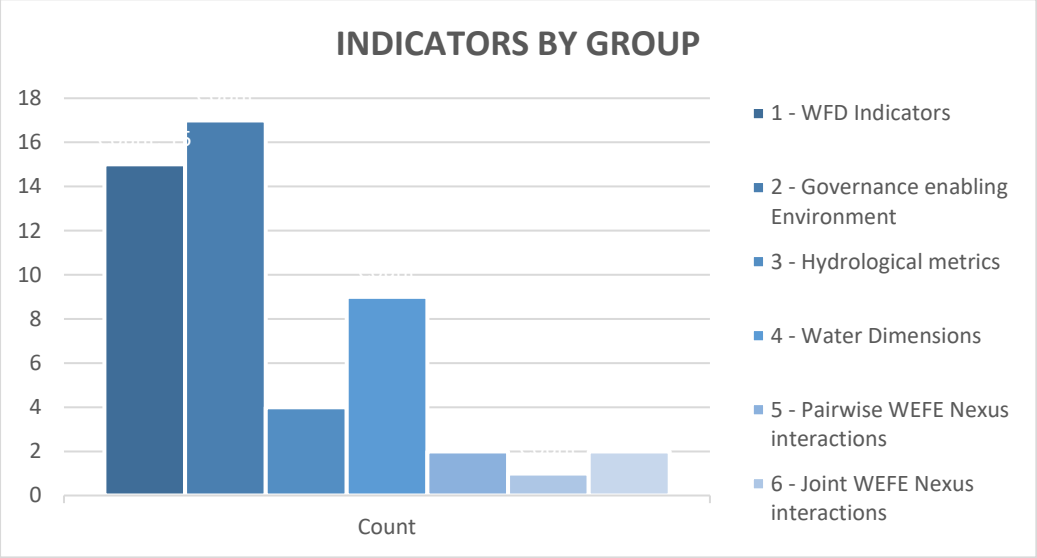


Figure 3. Classification of indicators within the monitoring framework.

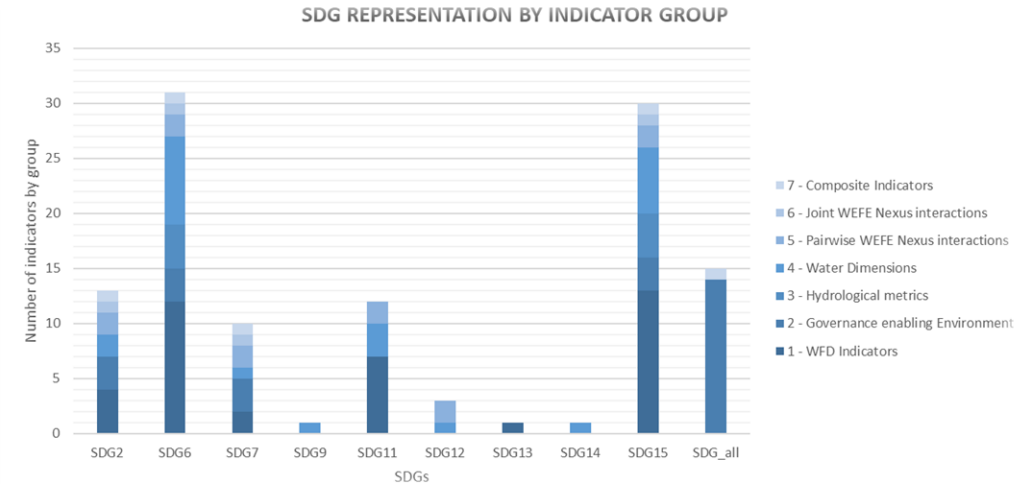


Figure 4. Indicator framework and links to the SDGs.

Preliminary step: adapting to the context

As previously mentioned, the list of indicators provided describes a general monitoring framework, which should be further adapted to reflect the context under assessment. This process is carried out

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

in three phases, and should aim at taking both a top-down and a bottom-up approach, with the support of expert opinion as well as stakeholder engagement mechanisms:

1. Reducing the provided shortlist – at this stage, decision makers should reflect on the context under assessment, and exclude those indicators that are not relevant to map it (e.g. in case there are no power plants using water in their processes, the "energy" dimension of the WEFE will have only a minor representation in the monitoring framework, if any). Experts and stakeholders can help exclude negligible attributes, as well as setting priorities for those that are relevant.
2. Integrating missing dimensions – the next step involves the exploration of additional potential variables that are not in the original shortlist, but that are necessary to represent the peculiarities of the context under evaluation.
3. Organizing the final indicators into groups – once the refined list is finalized, indicators should be grouped based on their characteristics. Such a grouping can rely on the original seven classes described in this deliverable, or on additional ones defined for this purpose. Grouping the indicators is useful for the next stage, where such clusters can provide alternatives to variables that cannot be accurately quantified.

Following these three steps, decision-makers obtain a complete, contextual, and representative set of indicators to assess water management in a specific setting, from a WEFE NEXUS perspective. The next section concerns the assessment of such indicators, which is carried out separately for qualitative and quantitative variables, and for each indicator's group.

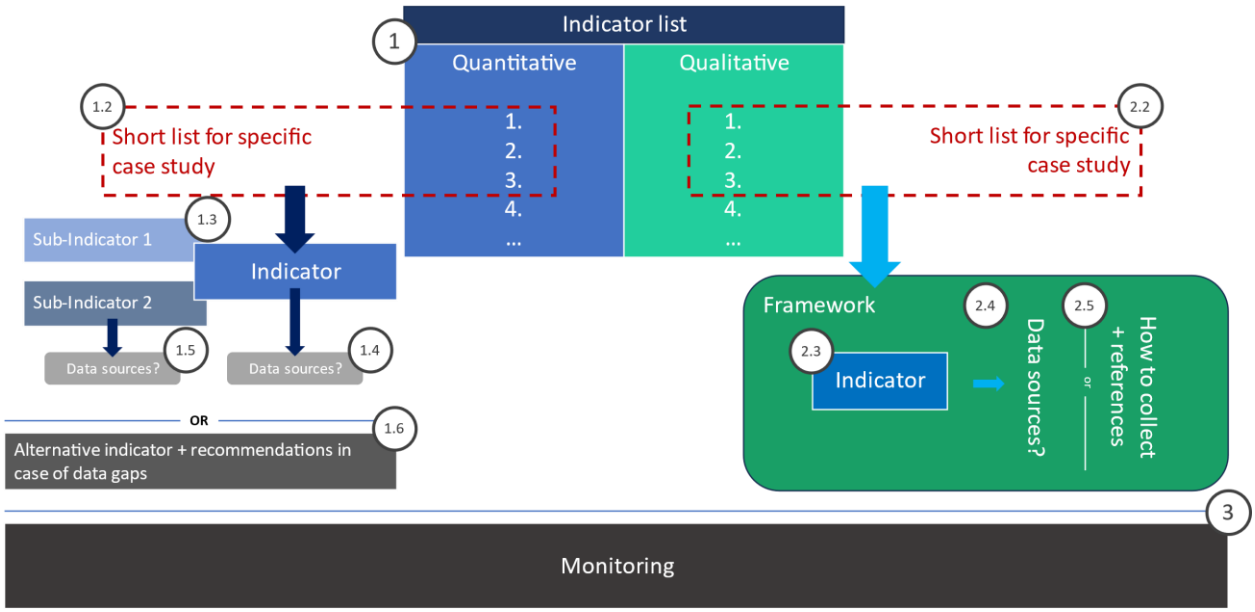


Figure 5. Assessment of indicators

Assessment

For the assessment of indicators within our monitoring framework, we propose a step-by-step procedure (Figure 5). The first step concerns the selection of the most relevant inidicators to the given

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

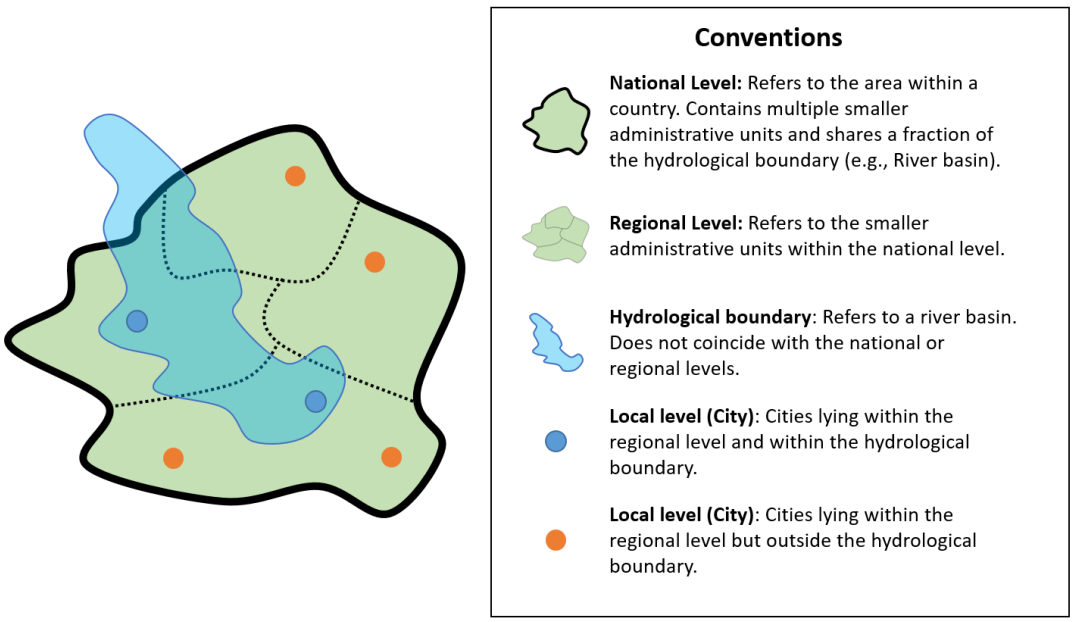
context, as described in the previous paragraph. This is done for both the qualitative and quantitative indicators. The subsequent steps vary depending on the type of indicator. Quantitative indicators can be calculated using the data sources reported in section 3. Nevertheless, it is important to clarify that in many cases publicly available data is only available at a high level of spatial aggregation. Still, the process of assessment can be done at certain levels for our indicators and the sub-indicators contained within. In some cases, where data is unavailable to assess an indicator, we propose alternative variables. For the qualitative indicators, publicly available data will rarely exist. These indicators should be obtained as part of a stakeholder engagement process. The next section describes in more detail data sources and potential uses for the indicators in our shortlist.

The issue of spatial scale

The Nexus literature emphasizes the importance of conducting multi-level assessments of governance systems. For example, the nature of WEFE node interactions at a regional level may have an impact on national and international levels (Liu *et al.*, 2018). By studying interactions across multiple levels, the Nexus approach aims to minimize, not only negative spillover across sectors but also across spatial levels. The idea is to avoid a situation in which achieving policy goals (for example SDGs) in one location generates adverse effects on the capacity of other areas to do as such (Liu *et al.*, 2018). In the context of water governance, one example of this type of interaction is the concept of virtual water, which represents the translocated water embedded in internationally traded commodities, which is usually not accounted for in the recipient country (Bidoglio *et al.,* 2019).

For this reason, it is crucial to incorporate a range of scales in water governance and Nexus assessments. In practice, these scales arise from multiple levels of geographical and administrative boundaries. The RETOUCH NEXUS project will consider the following (Figure 6):

- National
- Regional
- Hydrological boundaries (area of influence of water bodies and river basins)
- Local (*e.g.*, cities, municipalities, business parks).



Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Figure 6. Relevant spatial scales for monitoring water governance

From Figure 6 it is clear that careful consideration of multiple scales is essential for monitoring water governance. Usually, indicators are relevant to multiple scales. However, their assessment depends strongly on the availability of data at finer or coarser levels. Furthermore, their assessment over different scales may provide contradictory information. For example, an indicator for water scarcity at the national level may suggest that water scarcity is not a concern. However, it is possible that water scarcity is an issue in a specific region. Another important consideration is that some indicators are only relevant for hydrological boundaries. However, hydrological boundaries and administrative units (e.g., sub national or local level) do not coincide.

The above discussion translates into the following challenge for the assessment of indicators and subsequent water governance monitoring: First, it is often not possible to find data at the local scale. Second, it is often not possible to find data at the same scale for all indicators. Despite this, in general it is important to strive to address multiple scales in a given analysis to improve comparability and identify techniques to downscale or upscale the available data.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

3. Available Data, Data Gaps and their Implications (Factsheets)

Quantitative Indicators – Publicly available data

Group 1 – EU Water Framework Directive					
1.1. Area/Length of water bodies where hydro morphological alterations [for …] are preventing the achievement of WFD objectives. Sub indicators: Agricultural purposes, Aquaculture purposes, Hydropower production, Public water supply, transport purposes.					
UDM		Reference		SDGs	
Km^2, Km		European Commission (2023)		2 | 6 | 7 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Freshwater Information System for Europe (WISE – freshwater)	WISE Freshwater (europa.eu)	Free		Country level and main European river basins (EU)
Secondary	Surface water significant pressures and Impacts	Surface water significant pressures and impacts (europa.eu)	Free		Country level and main European river basins (EU)
Secondary	Groundwater significant pressures and impacts	Groundwater significant pressures and impacts (europa.eu)	Free		Country level and main European river basins (EU)
Alternative indicators in case no data are available: - Surface water significant pressures and impacts (Number of water bodies and area) - Groundwater significant pressures and impacts (Number of water bodies and area)					
How to use:					
The indicator is used to identify the main pressures and impacts to water bodies.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 1 – EU Water Framework Directive					
1.2. Area of water bodies where physical loss of habitats is preventing the achievement of objectives.					
UDM		Reference		SDGs	
Km^2, Km		European Commission (2023)		2 | 6 | 7 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Freshwater Information System for Europe (WISE – freshwater)	WISE Freshwater (europa.eu)	Free		Country level and main European river basins (EU)
Secondary	Surface water significant pressures and Impacts	Surface water significant pressures and impacts (europa.eu)	Free		Country level and main European river basins (EU)
Secondary	Groundwater significant pressures and impacts	Groundwater significant pressures and impacts (europa.eu)	Free		Country level and main European river basins (EU)
Alternative indicators in case no data are available: - Surface water significant pressures and impacts (Number of water bodies and area) - Groundwater significant pressures and impacts (Number of water bodies and area)					
How to use:					
The indicator is used to identify the main pressures and impacts to water bodies.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 1 – EU Water Framework Directive					
1.3. Number of sites associated with [] preventing the achievement of objectives. Sub indicators: Drinking water, Flood Protection, Hydropower, Industry, Irrigation, Other uses (Navigation, recreation)					
UDM		Reference		SDGs	
Number of sites		European Commission (2023)		2 | 6 | 7 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Freshwater Information System for Europe (WISE – freshwater)	WISE Freshwater (europa.eu)	Free		Country level and main European river basins (EU)
Secondary	Surface water significant pressures and Impacts	Surface water significant pressures and impacts (europa.eu)	Free		Country level and main European river basins (EU)
Secondary	Groundwater significant pressures and impacts	Groundwater significant pressures and impacts (europa.eu)	Free		Country level and main European river basins (EU)
Alternative indicators in case no data are available: - Surface water significant pressures and impacts (Number of water bodies and area) - Groundwater significant pressures and impacts (Number of water bodies and area)					
How to use:					
The indicator is used to identify the main pressures and impacts to water bodies.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 1 – EU Water Framework Directive					
1.4. Area of [] required to be covered by measures to achieve WFD Objectives. Sub indicators: Water bodies, Agricultural land, Forest land					
UDM		Reference		SDGs	
Km^2, Km		European Commission (2023)		2 | 6 | 7 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Freshwater Information System for Europe (WISE – freshwater)	WISE Freshwater (europa.eu)	Free		Country level and main European river basins (EU)
Secondary	Surface water significant pressures and Impacts	Surface water significant pressures and impacts (europa.eu)	Free		Country level and main European river basins (EU)
Secondary	Groundwater significant pressures and impacts	Groundwater significant pressures and impacts (europa.eu)	Free		Country level and main European river basins (EU)
Alternative indicators in case no data are available: - Surface water significant pressures and impacts (Number of water bodies and area) - Groundwater significant pressures and impacts (Number of water bodies and area)					
How to use:					
The indicator is used to identify the main pressures and impacts to water bodies.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 1 – EU Water Framework Directive					
1.5. Area/length of water bodies/river networks required to be restored or reconnected to floodplains to achieve objectives.					
UDM		Reference		SDGs	
Km^2, Km		European Commission (2023)		2 | 6 | 7 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Freshwater Information System for Europe (WISE – freshwater)	WISE Freshwater (europa.eu)	Free		Country level and main European river basins (EU)
Secondary	Surface water significant pressures and Impacts	Surface water significant pressures and impacts (europa.eu)	Free		Country level and main European river basins (EU)
Secondary	Groundwater significant pressures and impacts	Groundwater significant pressures and impacts (europa.eu)	Free		Country level and main European river basins (EU)
Alternative indicators in case no data are available: - Surface water significant pressures and impacts (Number of water bodies and area) - Groundwater significant pressures and impacts (Number of water bodies and area)					
How to use:					
The indicator is used to identify the main pressures and impacts to water bodies.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 1 – EU Water Framework Directive					
1.6. Number of contaminated sites preventing the achievement of objectives.					
UDM		Reference		SDGs	
Number of sites		European Commission (2023)		2 | 6 | 7 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Freshwater Information System for Europe (WISE – freshwater)	WISE Freshwater (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 1	Surface Water Ecological Status	Surface water ecological status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 2	Surface Water Chemical Status	Surface water chemical status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 3	Groundwater chemical status	Groundwater chemical status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 4	Groundwater quantitative status	Groundwater quantitative status (europa.eu)	Free		Country level and main European river basins (EU)
Alternative indicators in case no data are available: Surface water Ecological status; Number/Area of surface water bodies failing to achieve Good Ecological Status; Surface water Chemical status; Number/Area of surface water bodies failing to achieve Good Chemical Status; Groundwater chemical status; Number/Area of groundwater bodies failing to achieve Good Chemical Status; Groundwater quantitative status; Number/Area of groundwater bodies failing to achieve Good quantitative Status.					
How to use:					
These indicators help to understand the main status and sources of contamination for water bodies.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 1 – EU Water Framework Directive					
1.7. Number of discharges not connected to sewerage network that are preventing the achievement of objectives.					
UDM		Reference		SDGs	
Number of sites		European Commission (2023)		2 | 6 | 7 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Freshwater Information System for Europe (WISE – freshwater)	WISE Freshwater (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 1	Surface Water Ecological Status	Surface water ecological status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 2	Surface Water Chemical Status	Surface water chemical status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 3	Groundwater chemical status	Groundwater chemical status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 4	Groundwater quantitative status	Groundwater quantitative status (europa.eu)	Free		Country level and main European river basins (EU)
Alternative indicators in case no data are available: Surface water Ecological status; Number/Area of surface water bodies failing to achieve Good Ecological Status; Surface water Chemical status; Number/Area of surface water bodies failing to achieve Good Chemical Status; Groundwater chemical status; Number/Area of groundwater bodies failing to achieve Good Chemical Status; Groundwater quantitative status; Number/Area of groundwater bodies failing to achieve Good quantitative Status.					
How to use:					
These indicators help to understand the main status and sources of contamination for water bodies.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 1 – EU Water Framework Directive					
1.8. Number of contaminated sites to be remediated or where preventative actions need to be taken to achieve objectives.					
UDM		Reference		SDGs	
Number of sites		European Commission (2023)		2 | 6 | 7 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Freshwater Information System for Europe (WISE – freshwater)	WISE Freshwater (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 1	Surface Water Ecological Status	Surface water ecological status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 2	Surface Water Chemical Status	Surface water chemical status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 3	Groundwater chemical status	Groundwater chemical status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 4	Groundwater quantitative status	Groundwater quantitative status (europa.eu)	Free		Country level and main European river basins (EU)
Alternative indicators in case no data are available: Surface water Ecological status; Number/Area of surface water bodies failing to achieve Good Ecological Status; Surface water Chemical status; Number/Area of surface water bodies failing to achieve Good Chemical Status; Groundwater chemical status; Number/Area of groundwater bodies failing to achieve Good Chemical Status; Groundwater quantitative status; Number/Area of groundwater bodies failing to achieve Good quantitative Status.					
How to use:					
These indicators help to understand the main status and sources of contamination for water bodies.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 1 – EU Water Framework Directive					
1.9. Number of drinking water protection zones required to achieve objectives.					
UDM		Reference		SDGs	
Number of sites		European Commission (2023)		2 | 6 | 7 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Freshwater Information System for Europe (WISE – freshwater)	WISE Freshwater (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 1	Surface Water Ecological Status	Surface water ecological status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 2	Surface Water Chemical Status	Surface water chemical status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 3	Groundwater chemical status	Groundwater chemical status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 4	Groundwater quantitative status	Groundwater quantitative status (europa.eu)	Free		Country level and main European river basins (EU)
Alternative indicators in case no data are available: Surface water Ecological status; Number/Area of surface water bodies failing to achieve Good Ecological Status; Surface water Chemical status; Number/Area of surface water bodies failing to achieve Good Chemical Status; Groundwater chemical status; Number/Area of groundwater bodies failing to achieve Good quantitative Status; Groundwater quantitative status; Number/Area of groundwater bodies failing to achieve Good quantitative Status.					
How to use:					
These indicators help to understand the main status and sources of contamination for water bodies.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 1 – EU Water Framework Directive					
1.10. Number of surface water interceptors and treatment facilities required to achieve objectives.					
UDM		Reference		SDGs	
Number of sites		European Commission (2023)		2 | 6 | 7 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Freshwater Information System for Europe (WISE – freshwater)	WISE Freshwater (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 1	Surface Water Ecological Status	Surface water ecological status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 2	Surface Water Chemical Status	Surface water chemical status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 3	Groundwater chemical status	Groundwater chemical status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 4	Groundwater quantitative status	Groundwater quantitative status (europa.eu)	Free		Country level and main European river basins (EU)
Alternative indicators in case no data are available: Surface water Ecological status; Number/Area of surface water bodies failing to achieve Good Ecological Status; Surface water Chemical status; Number/Area of surface water bodies failing to achieve Good Chemical Status; Groundwater chemical status; Number/Area of groundwater bodies failing to achieve Good quantitative Status; Groundwater quantitative status; Number/Area of groundwater bodies failing to achieve Good quantitative Status.					
How to use:					
These indicators help to understand the main status and sources of contamination for water bodies.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 1 – EU Water Framework Directive					
1.11. Number of waste disposal sites required to be upgraded or remediated to achieve objectives.					
UDM		Reference		SDGs	
Number of sites		European Commission (2023)		2 | 6 | 7 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Freshwater Information System for Europe (WISE – freshwater)	WISE Freshwater (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 1	Surface Water Ecological Status	Surface water ecological status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 2	Surface Water Chemical Status	Surface water chemical status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 3	Groundwater chemical status	Groundwater chemical status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 4	Groundwater quantitative status	Groundwater quantitative status (europa.eu)	Free		Country level and main European river basins (EU)
Alternative indicators in case no data are available: Surface water Ecological status; Number/Area of surface water bodies failing to achieve Good Ecological Status; Surface water Chemical status; Number/Area of surface water bodies failing to achieve Good Chemical Status; Groundwater chemical status; Number/Area of groundwater bodies failing to achieve Good quantitative Status; Groundwater quantitative status; Number/Area of groundwater bodies failing to achieve Good quantitative Status.					
How to use:					
These indicators help to understand the main status and sources of contamination for water bodies.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 1 – EU Water Framework Directive					
1.12. Number of wastewater treatment works requiring to be constructed or upgraded to achieve objectives.					
UDM		Reference		SDGs	
Number of sites		European Commission (2023)		2 | 6 | 7 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Freshwater Information System for Europe (WISE – freshwater)	WISE Freshwater (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 1	Surface Water Ecological Status	Surface water ecological status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 2	Surface Water Chemical Status	Surface water chemical status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 3	Groundwater chemical status	Groundwater chemical status (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 4	Groundwater quantitative status	Groundwater quantitative status (europa.eu)	Free		Country level and main European river basins (EU)
Alternative indicators in case no data are available: Surface water Ecological status; Number/Area of surface water bodies failing to achieve Good Ecological Status; Surface water Chemical status; Number/Area of surface water bodies failing to achieve Good Chemical Status; Groundwater chemical status; Number/Area of groundwater bodies failing to achieve Good quantitative Status; Groundwater quantitative status; Number/Area of groundwater bodies failing to achieve Good quantitative Status.					
How to use:					
These indicators help to understand the main status and sources of contamination for water bodies.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 1 – EU Water Framework Directive					
1.13. Area of [] where water pricing policy measures are required to achieve the objectives of WFD Article 9 (Cost Recovery). Sub indicators: Water bodies, Agricultural land, Forest land					
UDM		Reference		SDGs	
Km^2, Km		European Commission (2023)		2 | 6 | 11 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Freshwater Information System for Europe (WISE – freshwater)	WISE Freshwater (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 1	Financial cost recovery - Households	Financial cost recovery by sector-households (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 2	Financial cost recovery - Agriculture	Financial cost recovery by sector-agriculture (europa.eu)	Free		Country level and main European river basins (EU)
Secondary 3	Financial cost recovery – Industry and Energy	Financial cost recovery by sector-agriculture (europa.eu)	Free		Country level and main European river basins (EU)
Alternative indicators in case no data are available: - Financial cost recovery – Households (% of cost recovery) - Financial cost recovery – Agriculture (% of cost recovery) - Financial cost recovery – Industry and Energy (% of cost recovery)					
How to use:					
This indicator helps to understand if the administrative costs of water supply are being recovered.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 1 – EU Water Framework Directive					
1.14. Number of installations where upgrades or improvements are required to achieve objectives.					
UDM		Reference		SDGs	
Number of sites		European Commission (2023)		6 | 11 | 13 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Freshwater Information System for Europe (WISE – freshwater)	WISE Freshwater (europa.eu)	Free		Country level and main European river basins (EU)
Secondary	Flood Risk Areas	Flood Risk Area Viewer (europa.eu)	Free		Country level and main European river basins (EU)
Alternative indicators in case no data are available: - Flood risk areas					
How to use:					
This indicator helps to identify the areas with significant risks due to climatic pressures.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 1 – EU Water Framework Directive					
1.15. Number of storm overflows required to be upgraded to achieve objectives.					
UDM		Reference		SDGs	
Number of sites		European Commission (2023)		6 | 11 | 13 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Freshwater Information System for Europe (WISE – freshwater)	WISE Freshwater (europa.eu)	Free		Country level and main European river basins (EU)
Secondary	Flood Risk Areas	Flood Risk Area Viewer (europa.eu)	Free		Country level and main European river basins (EU)
Alternative indicators in case no data are available: - Flood risk areas					
How to use:					
This indicator helps to identify the areas with significant risks due to climatic pressures.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 3 – Hydrological metrics					
Evapotranspiration (ET)					
3.1. Measures the amount of water on the earth's surface that is converted to vapor including crop transpiration. May be computed as actual evapotranspiration or potential evapotranspiration.					
UDM	Reference		SDGs		
mm d^{-1} ; mm mo^{-1} ; mm y^{-1}	Allen et al. (1998); Neitsch et al. (2011); Francesconi et al. (2016); Garcia-Prats et al. (2023)		6 | 13 | 15		
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	ERA5-Land Hourly/monthly	Muñoz-Sabater et al. (2021)	CDS API; EE API	Data is in m of eq. water	Grid of 1 km^2 ;River basin; National level; Subnational level (Global)
Secondary	Other remote sensing and weather station data	Pettorelli (2019); Garcia-Prats et al. (2023)	Free	Several options	
Relevant indicators in case no data are available: Meteorological data (temperature, rainfall…), vegetation status, land use, land cover, crop water use					
How to use:					
Evapotranspiration is a key component in the water balance within the soil-plant-atmosphere continuum. Potential evapotranspiration is the amount of water that would evaporate and transpire when the atmospheric evaporative demand is less than or equal to the available water. In contrast, actual ET reflects the real conditions of water availability. Evapotranspiration can be obtained from the use of equations; such as Penman-Monteith equation (Pereira et al., 2006), remote sensing, weather stations, sensors, etc. Among these methods, the Penman-Monteith is widely used for calculating ET, considering factors like temperature, solar radiation, wind speed, and humidity (Allen et al., 1998). This metric can be used for various purposes. As illustration, ET is used in irrigation scheduling, hydrological modelling, drought assessment, and assessing the water requirements of crops. Additionally, it can serve as a parameter to map water availability, it is strongly linked with land use, land cover, climate and ecosystem regulation (Pettorelli, 2019). Evapotranspiration is a key factor in formulating indices such as the Standardized Precipitation-Evapotranspiration Index (SPEI). The SPEI is designed as a composite index to address a limitation found in the Standardized Precipitation Index (SPI), which fails at accounting for temperature's impact when characterizing droughts within the framework of a changing climate. While the SPI's foundation is similar, the SPEI modifies the approach by integrating precipitation with the deduction of potential evapotranspiration (PET). This modification renders the SPEI a more effective tool for the accurate depiction of drought conditions, particularly in regions with arid or semi-arid climates, or in scenarios influenced by climate change, as noted by Vicente-Serrano et al. in 2012.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 3 – Hydrological metrics					
Aquifer Recharge Rate Index (ARRI)					
3.2. Measures the rate at which the aquifer is replenished with water. It provides information about the amount of water that enters the aquifer through natural processes such as precipitation, surface water infiltration and deep percolation.					
UDM	Reference		SDGs		
mm y^{-1}; $m^3 y^{-1}$	Levintal et al. (2023); Rodell et al. (2009); Stettz et al. (2022); Scanlon et al. (2021), (2002); Dillon and Arshad (2016);		6 | 13 | 15		
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	GRACE Satellite data	Rodell et al. (2009); Stettz et al. (2022);	NASA API	Measures changes in groundwater storage, soil moisture…	River basin; National level; Subnational level (Global)
Secondary	Groundwater observation wells	Scanlon et al. (2021), (2002)	Various national and local agencies	Direct measurements of groundwater levels	
Relevant indicators in case no data are available: Precipitation data, land use and cover, soil moisture data					
How to use:					
The use of the Aquifer Recharge Rate Index (ARRI) is essential for assessing the groundwater resource sustainability. It evaluates the balance between groundwater extraction and natural replenishment, thereby helping in the effective management of water resources, particularly in regions dependent on groundwater for agriculture, drinking water, and industrial purposes. This indicator is crucial for predicting the impacts of drought and climate change on water availability and for planning sustainable water use practices (Dillon and Arshad, 2016; Levintal et al., 2023). ARRI is related and affected by several factors such as soil type, vegetation cover, climate conditions, and land use.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

<table>
<tr><th colspan="6">Group 3 – Hydrological metrics</th></tr>
<tr><td colspan="6">Standardized Runoff Index (SRI)</td></tr>
<tr><td colspan="6">3.3. The Standardized Runoff Index (SRI) is used to evaluate and characterize hydrological droughts. It's similar to the well-known Standardized Precipitation Index (SPI), but while the SPI is based on precipitation alone, the SRI incorporates hydrologic processes that account for seasonal lags in the influence of climate on streamflow.</td></tr>
<tr><td>UDM</td><td colspan="3">Reference</td><td colspan="2">SDGs</td></tr>
<tr><td>Dimensionless</td><td colspan="3">Vicente-Serrano et al. (2012); Shukla and Wood 2008); Nalbantis and Tsakiris (2009);</td><td colspan="2">6 | 13 | 15</td></tr>
<tr><td>Data sources</td><td>Name</td><td>Reference</td><td>Access</td><td>Notes</td><td>Resolution (Scale)</td></tr>
<tr><td>Primary</td><td>Gauging stations; Sensors;</td><td>(Shukla and Wood, 2008); (Vicente-Serrano et al., 2012)</td><td>National hydrological services</td><td rowspan="2">- Continuous data on river flow
- Provides runoff estimates</td><td rowspan="2">River basin (Global)</td></tr>
<tr><td>Secondary</td><td>Climate models; Remote sensing; Hydrological models;</td><td>(Vicente-Serrano et al., 2012)</td><td>Depend</td></tr>
<tr><td colspan="6">Relevant indicators in case no data are available: Land characteristics (texture, structure, use, slope...), soil moisture, Precipitation data, evapotranspiration</td></tr>
<tr><td colspan="6">How to use:</td></tr>
<tr><td colspan="6">Also known as the Standardized Streamflow Index (SSI), can be calculated from wide range of possibilities including sensors, gauging stations, and hydrological models and is applied to hydrological discharge, surface runoff, and streamflow (Shukla and Wood, 2008). Used to assess the availability of water resources in river basins, highlights periods of low runoff (droughts) and high runoff (floods), supporting water management strategies and disaster response planning. Also used to study the effects of land use changes and climate variability on water resources. To calculate, normalize runoff values over a specific period to account for seasonal and climatic variations (Shukla and Wood, 2008; Vicente-Serrano et al., 2012). It is forecastable, relying on both climate projections and hydrologic conditions that often dictate runoff outcomes, like the spring snowpack in the western US. Calibrated runoff simulations are more accessible for immediate use than modified streamflow data, making them more practical for real-time analysis (Shukla and Wood, 2008).</td></tr>
</table>

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 3 – Hydrological/Agricultural metrics					
Water Productivity (WP)					
3.4. Measures the efficiency of water use in terms of output or yield per unit of water consumed.					
UDM	Reference		SDGs		
Kg m^{-3}; € m^{-3}	Lorite et al. (2004); Molden (2013); Bastiaanssen et al. (2000); Zwart and Bastiaanssen (2004); Raes et al. (2009); Steduto et al. (2012), (2009)		2 | 6 | 12 | 13 | 15		
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Agronomic models (e.g., FAO AquaCrop)	Steduto et al. (2012); Raes et al. (2009)	Publicly available	Crop-specific water productivity models	Plot scale; Regional scale (Global)
Secondary	Remote sensing data (e.g., MODIS, Landsat)	Bastiaanssen et al. (2000)	Free	Estimates of biomass production and evapotranspiration	
Relevant indicators in case no data are available: Irrigation water use data, Crop yield data, industrial water consumption, water use efficiency					
How to use:					
WP is a crucial indicator for assessing the efficiency of water use in agriculture and other sectors. It helps in determining how effectively water resources are being used to produce food, goods, or economic value. Higher WP indicates better water use efficiency. The calculation of this indicator involves dividing the output, for example crop yield or economic value, by the amount of water consumed. WP is influenced by several factors such as irrigation practices, crop type, soil properties, and climate conditions. It helps in improving irrigation management and water conservation strategies (Lorite et al., 2004; Steduto et al., 2012).					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 4 – Specific water dimensions					
Soil Organic Carbon (SOC)					
4.1. Measures the concentration of soil organic carbon in the top X cm of soil.					
UDM	Reference		SDGs		
% on the top X cm of soil	UNCCD Science-Policy Interface (2019)		6 | 15		
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	FAO Soil Portal: Global Soil Organic Carbon Map	Food and Agriculture Organisation of the United Nations (2024)	Free	SOC Stock Unit in 0-30 cm of soil (tonnes/ha)	National (with multiple observations per country) (Global)
Secondary	A global database of land management, land-use change and climate change effects on soil organic carbon	Beillouin et al. (2022)	Free	Meta-analysis of land-use effects on SOC	National; regional (Global)
Alternative indicators in case no data are available: Altitude, land cover, topsoil texture, and soil type					
How to use:					
Soil organic carbon (SOC) is the main component of soil organic matter (SOM) and is a crucial contributor to food production, mitigation and adaption to climate change, and the achievement of the Sustainable Development Goals (SDGs). (FAO, 2018)(Food and Agriculture Organisation of the United Nations 2018)					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 4 – Specific water dimensions					
Soil erosion rate					
4.2. Refers to the rate at which land surface wears away due to physical forces (rainfall, water, wind, anthropogenic).					
UDM	Reference		SDGs		
T ha^{-1} y^{-1}	Ministry of Agriculture and Rural Development of the Slovak Republic (2023)		6 | 15		
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Dataset: countries and the global rate of soil erosion	Wuepper et al. (2020)	Free	tonnes per hectare per year	National (with multiple observations per country) (Global)
Secondary	SoilErosionDB	Jian et al. (2020)	Free	tonnes per hectare per year	National (Global)
Alternative indicators in case no data are available: Surface runoff observations, nutrient leaching					
How to use:					
Soil erosion is a major threat to food security and ecosystem viability, as current rates are orders of magnitude higher than natural soil formation. Governments around the world are trying to address the issue of soil erosion (Wuepper et al. 2020).					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 4 – Water Dimensions					
Falkenmark or Water Stress Index (WSI)					
4.3. Measures the amount of available renewable freshwater resources per capita after considering environmental flow requirements. Sub-indicators: this indicator may be disaggregated among multiple water sources (groundwater, surface water or recycled wastewater).					
UDM		Reference		SDGs	
$m^3\ ha^{-1}\ y^{-1}$; $m^3\ ha^{-1}\ m^{-1}$		Damkjaer and Taylor (2017)		6 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Aquastat	FAO (2024)	Free	Only until 2020	National (Global)
Secondary	Community Water Model - CWatM	Burek et al. (2020)	Free	Complex model	Sub-basin (Global)
Alternative indicators in case no data are available: the interested researcher could combine data on available water with population data to have a rough estimate of a water stress measure					
How to use:					
The index can provide a comparable measure of water scarcity at various scales.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 4 – Water Dimensions					
Water Withdrawals to Availability ratio (WTA ratio) or Water Exploitation Index + (WEI+)					
4.4. Measures the consumption of water as a percentage of available renewable freshwater resources. Here, consumption considers domestic, industrial, and agricultural water withdrawals. To account for ecosystems, water availability is corrected by subtracting environmental flow requirements. Sub-indicators: This indicator may be disaggregated among multiple water sources (groundwater, surface water or recycled wastewater).					
UDM		Reference		SDGs	
Ratio (% of available freshwater)		Karabulut et al. (2016) ; Damkjaer and Taylor (2017)		2 | 6 | 7 | 9 | 11 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	WEI+ : EEA	European Environment Agency (2024) | Eurostat (2024)	free	only until 2019	National (EU)
Secondary 1	WEI+ : EEA	European Environment Agency (2023b)	free	2019 values, sub-basin reference codes to be interpreted	Sub-river basin (EU)
Secondary 2	WEI+ : EEA	European Environment Agency (2018)	free	2015 values, vector data	River basin (EU)
Alternative indicators in case no data are available: high resolution WEI from Burek et al. (2020), it is a complex model however					
How to use:					
The indicator is a standardized, commonly accepted, comparable measure of water scarcity.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

<table>
<tr><th colspan="6">Group 4 – Water Dimensions</th></tr>
<tr><td colspan="6">Matching Degree of Water Land Resources (MDWL)</td></tr>
<tr><td colspan="6">4.5. This indicator measures the amount of water resources used by agricultural land unit. This is:

MDWL = (Total water resources*proportion of agricultural water consumption) / (agricultural area).

Sub-indicators: This indicator may be disaggregated among multiple water sources (groundwater, surface water or recycled wastewater).</td></tr>
<tr><td colspan="2">UDM</td><td colspan="2">Reference</td><td colspan="2">SDGs</td></tr>
<tr><td colspan="2">m^3 ha^{-1}</td><td colspan="2">Zhao et al. (2018) ; Arthur et al. (2019)</td><td colspan="2">2 | 6 | 14</td></tr>
<tr><td>Data sources</td><td>Name</td><td>Reference</td><td>Access</td><td>Notes</td><td>Resolution (Scale)</td></tr>
<tr><td>Primary</td><td>Own calculation</td><td>Total water resources : FAO (2024) | Eurostat (2022)

% of agricultural water consumption : Khan et al. (2023)

Agricultural area (land cover) : European Environment Agency (2023a)</td><td>free</td><td>Use the three inputs to calculate MDWL.

CORINA land cover only until 2018</td><td>National (EU)</td></tr>
<tr><td colspan="6">Alternative indicators in case no data are available: Water for agriculture, as in Khan et al. (2023)</td></tr>
<tr><td colspan="6">How to use:</td></tr>
<tr><td colspan="6">The indicator gives an idea of the impact that the agricultural activity has on water use.</td></tr>
</table>

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 4 – Water Dimensions					
Water Retention Capacity of Soil					
4.6. Measures the capacity of the soil to accumulate water.					
UDM		Reference		SDGs	
m^3 ha^{-1}		Ministry of Agriculture and Rural Development of the Slovak Republic (2023)		6 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Volumetric water retention	Turek et al. (2023)	Free	Until 2016, files in GeoTIF format	250m (Global)
Secondary	Field capacity	Zhang et al. (2018)	Free	Files in GeoTIF format	1Km, 0-5cm (Global)
Alternative indicators in case no data are available: soil humidity Han et al. (2023)					
How to use:					
The indicator is fundamental to assess the interaction between water and soil quality, which has important consequences for the Food and Ecosystems elements of the WEFE.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

<table>
<tr><th colspan="6">Group 4 – Water Dimensions</th></tr>
<tr><td colspan="6">Cost recovery of water services</td></tr>
<tr><td colspan="6">4.7. Measures the percentage of administrative and operating costs of water provision service that is recovered through policy pricing measures. Considers the following sectors: Energy production, Agriculture (irrigation), Domestic consumption, Industrial Consumption.

Sub-indicators: This indicator may be disaggregated among multiple water sources (cost recovery of groundwater use, surface water use or recycled wastewater use).</td></tr>
<tr><td colspan="2">UDM</td><td colspan="2">Reference</td><td colspan="2">SDGs</td></tr>
<tr><td colspan="2">% of water service cost that is recovered through pricing measures</td><td colspan="2">(Financing Water Supply, Sanitation and Flood Protection 2020)</td><td colspan="2">6 | 11 | 17</td></tr>
<tr><td>Data sources</td><td>Name</td><td>Reference</td><td>Access</td><td>Notes</td><td>Resolution (Scale)</td></tr>
<tr><td>Primary</td><td>EAA - Cost recovery service rates for:
Households
Energy
Agriculture</td><td>European Environment Agency (2021)</td><td>Free</td><td>Data are in .SQLite format</td><td>River-basin (EU)</td></tr>
<tr><td>Secondary</td><td>Self calculating the indicator</td><td>With cost and pricing data for water management</td><td>Depending on the source</td><td>Quite complicated and time consuming</td><td>Variable</td></tr>
<tr><td colspan="6">Alternative indicators in case no data are available: Water pricing data from local administration (Not always available)</td></tr>
<tr><td colspan="6">How to use:</td></tr>
<tr><td colspan="6">This indicator can be used to evaluate the economic sustainability of water management in a context.</td></tr>
</table>

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 4 – Water Dimensions					
Water Economic Productivity					
4.8. Measures how much water is used to produce a given output (in monetary value). Considers outputs from the following sectors: Energy production (by energy resource), Food and agriculture (by commodity). Sub-indicators: This indicator may be disaggregated among multiple water sources (groundwater use, surface water use or recycled wastewater use).					
UDM		Reference		SDGs	
m^3 $\$^{-1}$		El-Gafy (2017) ; Arthur et al. (2019)		6 | 11	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Water productivity	World Bank Open Data (2024)	Free		National (Global)
Secondary	Water productivity for agriculture: self calculation	Water productivity for agriculture: Extending model from Cheng et al. (2022)	Free	Time consuming	1 km
Alternative indicators in case no data are available:					
How to use:					
This indicator links water use and the productive activities across multiple sectors, from an economic point of view.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 4 – Water Dimensions					
Environmental Flow Requirements					
4.9. Measures the amount (flow) of water required to maintain healthy freshwater-dependent ecosystems in river basins.					
UDM		Reference		SDGs	
Volume (10^6 m3) per month		Karabulut et al. (2016)		15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Zenodo	Xingcai Liu (2024)	Free	Multiple models output; $m^3 s^{-1}$	0.5° (Global)
Secondary	AQUASTAT	FAO (2024)	Free		National (Global)
Alternative indicators in case no data are available: Environmental Flow Envelopes Virkki et al. (2022)					
How to use:					
This is the fraction of water that is necessary for ecosystems to be maintained. It is important to account for this dimension when discussing about the WEF**E** NEXUS since ignoring it would leave a fraction of water withdrawals unaccounted for.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 5 – Pairwise WEFE Nexus interactions					
Cross-sectoral water flow quantities					
5.1. Measures the amount of water used by each sector. Including the following: Energy related water usage (by energy source), Food related water usage (by crop/livestock production), Industrial water usage (excluding energy), Domestic water usage. Sub-indicators: This indicator may be disaggregated among multiple water sources (groundwater use, surface water use or recycled wastewater use).					
UDM		Reference		SDGs	
Volume (10^6 m3) per month		Karnib (2018)		2 | 6 | 7 | 11 | 12 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Publication	Khan et al. (2023)	Free		0.5°, 2010-2100 (Global)
Secondary	AQUASTAT	FAO (2024)	Free		National (Global)
Alternative indicators in case no data are available:					
How to use:					
This metric can be used to describe water use across sectors with more or less detail.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 5 – Pairwise WEFE Nexus interactions					
Cross-sectoral Water Use Intensities (Water Footprint)					
5.2. Measures the amount of water used to produce one unit of output of another sector. Considering the following: Energy related water usage (by energy source), Food related water usage (by commodity). Sub-indicators: This indicator may be disaggregated among multiple water sources (groundwater use intensity, surface water use or recycled wastewater use intensity).					
UDM		Reference		SDGs	
$m^3\ t^{-1}$ or $m^3\ Wh^{-1}$ (Energy), $m^3\ t^{-1}$ (Food).		Karnib (2018)		2 | 6 | 7 | 11 | 12 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Water Footprint	Mekonnen and Hoekstra (2011)	Free	Tables in PDF format in annex, only until 2005	National (Global)
Alternative indicators in case no data are available: Water use by sector (Khan et al. 2023)					
How to use:					
Provides a socioeconomic perspective on the use of water more easily comparable with production.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 6 – Joint WEFE Nexus interactions					
WEFE WTA Ratio					
6.1. The WEFE Water Withdrawals to Availability (WTA) ratio is the proportion of available renewable freshwater resources employed for food and energy. To account for ecosystems, water availability is corrected by subtracting environmental flow requirements. Sub-indicators: This indicator may be disaggregated among multiple water sources (groundwater, surface water or recycled wastewater). Furthermore, ratios may be computed disaggregating food into different commodities and energy into different sources.					
UDM		Reference		SDGs	
% of available renewable freshwater resources		Karabulut et al. (2016)		2 | 6 | 7 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	Publication	Khan et al. (2023)	Free		0.5°, 2010-2100 (Global)
Secondary	AQUASTAT	FAO (2024)	Free		National (Global)
Alternative indicators in case no data are available:					
How to use:					
This metric can be used to describe water use across sectors with more or less detail and understand trade-offs among water using sectors.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 7 – Composite Indicators					
WEF Nexus Index					
7.1. Composite indicator using 21 SDG-related indicators					
UDM		Reference		SDGs	
Composite Indicator (Index)		Simpson et al. (2022)		2 | 6 | 7 | 15	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	WEF Nexus Index dataset	Simpson (2020)	Free	Dated to 2020	National (Global)
Secondary	Self calculation following instructions	Simpson et al. (2022)	Free	Time consuming	National
Alternative indicators in case no data are available:					
How to use:					
The index describes countries in terms of the security and availability of water, food, and energy resources. It allows to quantitatively compare them under such multidimensional perspective.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 7 – Composite Indicators					
National Water Security Index					
7.2. Composite Indicator considering 5 dimensions: Rural Household Water Security, Economic Water Security, Urban Water Security, Environmental Water Security, Water-related Disaster Security.					
UDM		Reference		SDGs	
Composite Indicator (Index)		Asian Development Bank (2020)		all	
Data sources	Name	Reference	Access	Notes	Resolution (Scale)
Primary	ADB report	Asian Development Bank (2020)	Free	Provided as PDF tables in 3 different years	National (Asian countries)
Secondary	Self calculation according to ADB methodology	Asian Development Bank (2020)	Free	Time consuming	National
Alternative indicators in case no data are available: National Water Security Score (MacAlister et al.)					
How to use:					
This index can be used to provide an overall sense of water security at the national level, across several sectors where water security is essential.					

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Qualitative Indicators – How to assess? – Guidance

Group 2 – Policy coherence	
Familiarity with a WEFE nexus or other integrated approach	
2.1. Is there any familiarity with a WEFE nexus or other integrated approach in the country involved? Sub indicators: International river basin scale, National Scale, Regional scale, Local scale	
Levels	Degree of consensus
• To a very large extent • To a large extent • To some extent • To little extent • To no extent	• Strong agreement • Agreement • Disagreement • Strong disagreement
How to assess:	
The assessment of this indicator requires engagement with stakeholders and relevant experts. There are two variables of interest: the levels and the degree of consensus. The level indicates the agreement with the premise, i.e., "familiarity with a WEFE nexus or other integrated approach in the country involved may be a stimulating factor for the further development of such approaches". The degree of consensus indicates whether there seems to be an agreement among the engaged stakeholders/experts. The nature of the indicator implies that the results may vary depending on the engaged experts/stakeholders. For this reason, it is very important to account for representatives of all groups of interest when doing the assessment.	
How to use:	
The assessed level of the indicator provides qualitative evidence on the perception of stakeholders on the extent to which there is familiarity with a WEFE nexus or other integrated approach in the country involved. However, the degree of consensus is key to understanding if the perceptions are heterogeneous among stakeholders. Furthermore, the indicator may be used to understand perceptions on the extent to which there is familiarity with a WEFE nexus approach or other integrated approach in the country involved at multiple scales (international river basin, national scale, regional scale and local scale).	

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 2 – Policy coherence	
Supportive scientific infrastructure	
2.2. Is there a supportive scientific infrastructure in place for a WEFE nexus or other type of integrated approach in the country involved?	
Levels	Degree of consensus
• To a very large extent • To a large extent • To some extent • To little extent • To no extent	• Strong agreement • Agreement • Disagreement • Strong disagreement
How to assess:	
The assessment of this indicator requires engagement with stakeholders and relevant experts. There are two variables of interest: the levels and the degree of consensus. The level indicates the agreement with the premise, i.e., "policy coherence is enhanced by a supportive scientific infrastructure for a WEFE nexus or other type of integrated approach". The degree of consensus indicates whether there seems to be an agreement among the engaged stakeholders/experts. The nature of the indicator implies that the results may vary depending on the engaged experts/stakeholders. For this reason, it is very important to account for representatives of all groups of interest when doing the assessment.	
How to use:	
The assessed level of the indicator provides qualitative evidence on the perception of stakeholders on the extent to which a supportive scientific infrastructure is in place for a WEFE nexus or other type of integrated approach in the country involved. However, the degree of consensus is key to understanding if the perceptions are heterogeneous among stakeholders.	

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

<table>
<tr><th colspan="2">Group 2 – Institutional settings</th></tr>
<tr><td colspan="2">Facilitation of a multi-level approach</td></tr>
<tr><td colspan="2">2.3. Do institutional settings facilitate a multi-level approach?

Sub indicators: International river basin scale, National Scale, Regional scale, Local scale</td></tr>
<tr><td>Levels</td><td>Degree of consensus</td></tr>
<tr><td>To a very large extent
To a large extent
To some extent
To little extent
To no extent</td><td>Strong agreement
Agreement
Disagreement
Strong disagreement</td></tr>
<tr><td colspan="2">How to assess:</td></tr>
<tr><td colspan="2">The assessment of this indicator requires engagement with stakeholders and relevant experts. There are two variables of interest: the levels and the degree of consensus. The level indicates the agreement with the premise, i.e., “appropriate institutional settings may facilitate a multi-level approach”. The degree of consensus indicates whether there seems to be an agreement among the engaged stakeholders/experts.

The nature of the indicator implies that the results may vary depending on the engaged experts/stakeholders. For this reason, it is very important to account for representatives of all groups of interest when doing the assessment.</td></tr>
<tr><td colspan="2">How to use:</td></tr>
<tr><td colspan="2">The assessed level of the indicator provides qualitative evidence on the perception of stakeholders on the extent to which institutional settings are facilitating a multi-level approach. However, the degree of consensus is key to understanding if the perceptions are heterogeneous among stakeholders.

Furthermore, the indicator may be used to understand perceptions on the extent to which institutional settings are facilitating a multi-level approach at multiple scales (international river basin, national scale, regional scale and local scale).</td></tr>
</table>

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 2 – Innovative governance	
Overarching and challenging policy paradigm	
2.4. Is governance built on an overarching and challenging policy paradigm to adhere to?	
Levels	Degree of consensus
• To a very large extent • To a large extent • To some extent • To little extent • To no extent	• Strong agreement • Agreement • Disagreement • Strong disagreement
How to assess:	
The assessment of this indicator requires engagement with stakeholders and relevant experts. There are two variables of interest: the levels and the degree of consensus. The level indicates the agreement with the premise, i.e., "innovative governance requires the presence of an overarching and challenging policy paradigm to adhere to". The degree of consensus indicates whether there seems to be an agreement among the engaged stakeholders/experts. The nature of the indicator implies that the results may vary depending on the engaged experts/stakeholders. For this reason, it is very important to account for representatives of all groups of interest when doing the assessment.	
How to use:	
The assessed level of the indicator provides qualitative evidence on the perceptions of stakeholders on the extent to which an overarching and challenging policy paradigm is in place that stimulates innovative governance. However, the degree of consensus is key to understanding if the perceptions are heterogeneous among stakeholders.	

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 2 – Innovative governance	
Testing of innovative governance practices	
2.5. Are any experiments being done with innovative governance practices?	
Levels	Degree of consensus
• To a very large extent • To a large extent • To some extent • To little extent • To no extent	• Strong agreement • Agreement • Disagreement • Strong disagreement
How to assess:	
The assessment of this indicator requires engagement with stakeholders and relevant experts. There are two variables of interest: the levels and the degree of consensus. The level indicates the agreement with the premise, i.e., "experiments are needed to test innovative governance practices". The degree of consensus indicates whether there seems to be an agreement among the engaged stakeholders/experts. The nature of the indicator implies that the results may vary depending on the engaged experts/stakeholders. For this reason, it is very important to account for representatives of all groups of interest when doing the assessment.	
How to use:	
The assessed level of the indicator provides qualitative evidence on the perceptions of stakeholders and on the extent to which experiments are taking place to test innovative governance practices. However, the degree of consensus is key to understanding if the perceptions are heterogeneous among stakeholders.	

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 2 – Innovative governance	
Exploration of new practical tools	
2.6. Are new practical tools being developed, applied and evaluated?	
Levels	Degree of consensus
• To a very large extent • To a large extent • To some extent • To little extent • To no extent	• Strong agreement • Agreement • Disagreement • Strong disagreement
How to assess:	
The assessment of this indicator requires engagement with stakeholders and relevant experts. There are two variables of interest: the levels and the degree of consensus. The level indicates the agreement with the premise, i.e., "new practical tools are needed to support the implementation of innovative governance practices". The degree of consensus indicates whether there seems to be an agreement among the engaged stakeholders/experts. The nature of the indicator implies that the results may vary depending on the engaged experts/stakeholders. For this reason, it is very important to account for representatives of all groups of interest when doing the assessment.	
How to use:	
The assessed level of the indicator provides qualitative evidence on the perceptions of stakeholders on the extent to which new practical tools are developed, applied and evaluated to support the implementation of innovative governance practices. However, the degree of consensus is key to understanding if the perceptions are heterogeneous among stakeholders.	

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

<table>
<tr><th colspan="2">Group 2 – Policy coherence</th></tr>
<tr><td colspan="2">Stakeholder perception - relevance</td></tr>
<tr><td colspan="2">2.7. Do stakeholders at the […] level consider the WEFE nexus approach relevant?
Sub indicators: International river basin scale, National Scale, Regional scale, Local scale</td></tr>
<tr><td>Levels</td><td>Degree of consensus</td></tr>
<tr><td>• Highly relevant
• Relevant
• Irrelevant
• Highly irrelevant</td><td>• Strong agreement
• Agreement
• Disagreement
• Strong disagreement</td></tr>
<tr><td colspan="2">How to assess:</td></tr>
<tr><td colspan="2">The assessment of this indicator requires engagement with stakeholders and relevant experts. There are two variables of interest: the levels and the degree of consensus. The level indicates the agreement with the premise, i.e., “stakeholders consider the WEFE nexus approach relevant”. The degree of consensus indicates whether there seems to be an agreement among the engaged stakeholders/experts. Thus, the indicator possesses significant importance regarding perception and scope of the WEFE nexus approach.

The nature of the indicator implies that the results may change depending on the engaged experts/stakeholders. For this reason, it is very important to account for representatives of all groups of interest when doing the assessment.</td></tr>
<tr><td colspan="2">How to use:</td></tr>
<tr><td colspan="2">The assessed level of the indicator provides qualitative evidence on the perception of stakeholders on the relevance of the WEFE nexus approach. However, the degree of consensus is key to understanding if the perceptions are heterogeneous among stakeholders.

Furthermore, the indicator may be used to understand perceptions on how relevant the approach is at multiple scales (international river basin, national scale, regional scale and local scale).</td></tr>
</table>

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

<table>
<tr><th colspan="2">Group 2 – Innovative governance</th></tr>
<tr><td colspan="2">Exchange platform for stakeholder feedback</td></tr>
<tr><td colspan="2">2.8. Is there a transparent and accessible platform for stakeholders, including responsible authorities to provide input and feedback on water laws, policies and regulations?</td></tr>
<tr><td>Accessibility</td><td>Degree of transparency</td></tr>
<tr><td>Yes
No</td><td>Fully transparent
Partially transparent
Not transparent</td></tr>
<tr><td colspan="2">How to assess:</td></tr>
<tr><td colspan="2">The assessment of this indicator requires engagement with stakeholders and responsible authorities. There are two variables of interest: the accessibility of a platform for stakeholders and its degree of transparency. The accessibility provides information if a platform is accessible to provide input and feedback on water laws, policies and regulations. The degree indicates to which extend such platform is transparent, e.g. regarding how feedback and inputs are used for the further development of water laws, policies and regulations. Exchange platforms possess significant importance as they provide an opportunity for stakeholders to engage with and impact on water laws, policies and regulations.

The nature of the indicator implies that the results may change depending on the engaged experts/stakeholders. For this reason, it is very important to account for representatives of all relevant stakeholders, including responsible authorities, when doing the assessment.</td></tr>
<tr><td colspan="2">How to use:</td></tr>
<tr><td colspan="2">The assessed accessibility of the indicator provides the basis for qualitative evidence on the degree of its transparency.

Furthermore, the indicator may be used to find out to which extent a transparent and accessible exchange platform for stakeholders is related to quality and acceptance of water laws, policies and regulations.</td></tr>
</table>

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 2 – Innovative governance	
Formalised mechanisms for public consultations	
2.9. Are there formalised mechanisms for public consultation and feedback during the water law or policy development?	
Existence	Degree of implementation
• Yes • No	• Fully implemented • Partial implement • Not implemented
How to assess:	
The assessment of this indicator requires engagement with stakeholders from the public sector. There are two variables of interest: the existence of formalised mechanisms for public consultation and feedback and the degree of their implementation. The existence indicates whether these mechanisms exist or not during the water law or policy development. The degree emphasises the level of their implementation, i.e., "formalised mechanisms for public participation and feedback are fully implemented". Public consultation and feedback processes possess significant importance as they provide an opportunity for stakeholders to engage with and impact on water law or policy development. These mechanisms have a greater scope as they are formalised and thus institutionalised. The nature of the indicator highlights the importance of public consultation and feedback during water law or policy development. For this reason, it is very important to account for various representatives from the public sector when doing the assessment.	
How to use:	
The assessed existence of the indicator provides the basis for qualitative evidence on the degree of its implementation. Furthermore, the indicator may be used to find out to which extent a formalised mechanisms for public consultation and feedback is related to the acceptance of new water laws or policy developments.	

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 2 – Innovative governance		
Conflicts of interest – management and disclosure		
2.10. Are conflicts of interest managed and disclosed among the responsible authorities and stakeholders involved in water law and policy making?		
Existence	Degree of conflict management	Degree of conflict disclosure
• Yes • No	• Fully managed • Partial managed • Not managed	• Fully disclosed • Partial disclosed • Not disclosed

How to assess:

The assessment of this indicator requires engagement with all responsible authorities and stakeholders involved in water law and policy making. There are three variables of interest: the existence of conflicts of interest among these stakeholders and the degree of conflict management and conflict disclosure. The existence indicates whether conflicts of interest exist or not. The degree of conflict management and the degree of conflict disclosure emphasize to what extend such conflicts are managed and subsequently disclosed, i.e., "conflicts of interest are fully managed and fully disclosed among responsible authorities and stakeholders involved in water law and policy making". Successful management and disclosure of conflicts of interest possesses significant importance as water law and policy making are characterized by compromise and solution orientation.

The nature of the indicator implies that the results may change depending on the engaged authorities and stakeholders. For this reason, it is very important to account for representatives of all groups of interest when doing the assessment.

How to use:

The assessed degree of the indicator provides qualitative evidence on the management and disclosure of conflicts of interest. This is key to understanding if and how conflicts are overcome by stakeholders.

Furthermore, the indicator may be used to find out to which extent the management of conflicts of interest is related to successfully disclose these conflicts.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 2 – Innovative governance	
Consultation of women and marginalised populations	
2.11. To what extent are women and marginalised populations consulted during policy or law development process?	
Existence	Degree of consultation
• Yes • No	• No consultation • Information supply • Consultation • Active involvement

How to assess:

The assessment of this indicator requires engagement with stakeholders, especially with women and marginalized populations. There are two variables of interest: the existence of consultation processes and the degree of consultation. The existence indicates whether women and marginalised populations are consulted during policy or law development processes. The degree of consultation highlights to which extend these groups are consulted, i.e., "women and marginalised populations are actively involved during policy or law development processes". Consultation of women and marginalized populations possesses significant importance as each stakeholder group commands specific needs.

The nature of the indicator implies that women and marginalized populations are at the centre of interest when doing the assessment.

How to use:

The assessed existence of the indicator provides the basis for qualitative evidence on the degree of consultation. However, the degree of consultation is key to understanding the nature of policy or law development processes.

Furthermore, the indicator may be used to find out to which extent the degree of consultation of women and marginalized populations during policy or law development processes is related to the acceptance of the latter.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 2 – Innovative governance	
Mechanisms to address identified water governance gaps	
2.12. Do mechanisms exist to address identified gaps in water governance when stakeholders bring them to attention?	
Existence	Degree of implementation
• Yes • No	• Fully implemented • Partial implement • Not implemented

How to assess:

The assessment of this indicator requires engagement with stakeholders and relevant experts. There are two variables of interest: the existence of mechanisms to address identified gaps and the degree of their implementation. The existence indicates whether such mechanisms exist in water governance when stakeholders bring them to attention or not. The degree highlights the level of their implementation, i.e., "mechanisms to address identified gaps in water governance are fully implemented". Mechanisms to address identified gaps possess significant importance as they provide an opportunity for stakeholders to bring them to attention and thus to engage with and to impact on water governance.

The nature of the indicator implies that the results may change depending on the engaged experts/stakeholders. For this reason, it is very important to account for representatives of all groups of interest when doing the assessment.

How to use:

The assessed existence of the indicator provides the basis for qualitative evidence on the degree of its implementation.

Furthermore, the indicator may be used to find out to which extent the existence and implementation of mechanisms to address identified gaps in water governance is related to quality and acceptance of policy or law development processes within water governance.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 2 – Stakeholder engagement	
Availability of required translations	
2.13. Are relevant information, policies, and any changes actively published and shared with stakeholders in all the required languages?	
Availability	Degree of active publishing and sharing
• Yes • No	• Full active publishing and sharing • Partial active publishing and sharing • No active publishing and sharing
How to assess:	
The assessment of this indicator requires engagement with stakeholders and experts in different languages. There are two variables of interest: the availability of relevant information, policies, and any changes in all the required languages and the degree of active publishing and sharing of these translations. The availability indicates if all stakeholders have access to the relevant documents in a language they understand. The degree highlights to which extend the relevant information is actively published and shared with stakeholders in the required language, i.e., "relevant information, policies, and any changes are fully actively published and shared with stakeholders in all the required languages". The availability of translations of relevant information, policies, and any changes possesses significant importance as it provides an opportunity for stakeholders to engage with and impact on water laws, policies and regulations. The nature of the indicator implies that the results may change depending on the engaged experts/stakeholders. For this reason, it is very important to account for representatives of all languages when doing the assessment.	
How to use:	
The assessed existence of the indicator provides the basis for qualitative evidence on the degree of active publishing and sharing. However, the degree is key to understanding to which extend relevant information, policies, and any changes are actively published and shared with stakeholders in all the required languages. Furthermore, the indicator may be used to find out how the availability of translations is related to the inclusion of stakeholders with different language backgrounds.	

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 2 – Stakeholder engagement	
Key performance indicators	
2.14. Are there key performance indicators (KPIs) to assess the success of targeted outreach strategies aimed at women, youth, and vulnerable groups?	
Existence	Degree of success
• Yes • No	• Successful • Partially successful • Not successful
How to assess:	
The assessment of this indicator requires engagement with different stakeholder groups, especially with women, youth, and vulnerable groups. There are two variables of interest: the existence of key performance indicators (KPIs) and the degree of success of targeted outreach strategies. The existence indicates whether KPIs are in place or not. The degree of success is key to assess the implementation of targeted outreach strategies with special emphasize on their target groups (women, youth, and vulnerable groups). Key performance indicators possess significant importance as they provide an opportunity to assess the success of targeted outreach strategies aimed at women, youth, and vulnerable groups. The nature of the indicator implies that the results may change depending on the engaged stakeholders. For this reason, it is very important to account for representatives of all groups of interest when doing the assessment.	
How to use:	
The assessed degree of the indicator provides qualitative evidence on the success of the targeted outreach strategy in relation to different stakeholder groups.	

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 2 – Stakeholder engagement	
Formal and informal stakeholder engagement mechanisms	
2.15. Are there formal and informal mechanisms to engage stakeholders?	
Existence	Degree of implementation
• Yes • No	• Fully implemented • Partial implement • Not implemented
How to assess:	
The assessment of this indicator requires engagement with stakeholders through different mechanisms. There are two variables of interest: the existence of formal and informal stakeholder engagement mechanisms and the degree of their implementation. The existence indicates whether these mechanisms exist or not. The degree indicates the level of their implementation, i.e., "formal and informal mechanisms are fully implemented". Formal as well as informal stakeholder engagement mechanisms possess significant importance as they provide an opportunity for stakeholders to engage with and impact on water law or policy development at different levels. The nature of the indicator implies that the results may change depending on the character (formal/informal) of the mechanism as well as on the time of implementation. For this reason, it is very important to account for a wide-ranging set of mechanisms and engagement opportunities at different time periods.	
How to use:	
The assessed existence of the indicator provides the basis for qualitative evidence on the degree of its implementation. Furthermore, the indicator may be used to understand which mechanisms (formal/informal) work best to engage different stakeholder groups.	

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 2 – Stakeholder engagement	
Joint stakeholder process	
2.16. Is the problem definition the result of a joint stakeholder process?	
Degree of inclusion	Degree of consensus
• Strong inclusion • Partial inclusion • Absent inclusion	• Full agreement • Partial agreement • Full disagreement
How to assess:	
The assessment of this indicator requires engagement with different stakeholder groups, especially with women, youth and vulnerable groups. There are two variables of interest: the degree of inclusion of different stakeholder groups and the degree of consensus. The degree of inclusion indicates whether the problem definition is the result of a strong, partial or absent joint stakeholder process. The degree of consensus emphasizes whether there seems to be an agreement on a problem definition among the engaged stakeholders, i.e., "there is full agreement that the problem definition is the result of a joint stakeholder process". Problem definition as the result of a joint stakeholder process possesses significant importance as it reflects specific needs of different stakeholder groups. The nature of the indicator implies that the results highly depending on the engaged stakeholder groups. For this reason, it is very important to account for representatives of all groups of interest when doing the assessment.	
How to use:	
The assessed degree of the indicator provides qualitative evidence on the joint character of the problem definition process among stakeholders. However, the degree of inclusion is key to understanding if the process was conducted collaborative. Furthermore, the indicator may be used to find out to which extent a collaborative process is related to finding a shared problem definition.	

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Group 2 – Stakeholder engagement	
Problem definition sharing	
2.17. Is the problem definition shared between stakeholders?	
Degree of sharing	Degree of consensus
• Fully shared • Partially shared • Not shared	• Full agreement • Partial agreement • Full disagreement
How to assess:	
The assessment of this indicator requires a basic level of understanding, transparency and trust among the stakeholders as well as willingness and openness to engage with different sector- or scale-related challenges. Problems can appear differently regarding meaning and importance to miscellaneous stakeholders but in order to resolve them effectively, it is crucial to share a common definition of the respective problem. There are two variables of interest: the degree of sharing and the degree of consensus. The degree of sharing indicates the agreement with the premise, i.e. "stakeholders fully share a common problem definition". The degree of consensus indicates whether there seems to be an agreement among the engaged stakeholders. To increase the possibility of finding a common definition, trade-offs should be revealed and synergies strengthened beforehand. The nature of the indicator implies that the results may change depending on the engaged stakeholders. For this reason, it is very important to account for representatives of all groups of interest when doing the assessment.	
How to use:	
The assessed degree of the indicator provides qualitative evidence on the agreement of stakeholders on a shared problem definition. However, the degree of consensus is key to understanding if (dis)agreements are heterogeneous among stakeholders. Furthermore, the indicator may be used to find out to which extent a shared problem definition is related to successfully overcoming the problem.	

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

<table>
<tr><th colspan="2">Group 2 – Stakeholder engagement</th></tr>
<tr><td colspan="2">Water allocation priorities</td></tr>
<tr><td colspan="2">Are prioritization principles for water allocation defined and agreed upon? Yes/No</td></tr>
<tr><td>Existence</td><td>Degree of consensus</td></tr>
<tr><td>Yes
No</td><td>Full agreement
Partial agreement
Full disagreement</td></tr>
<tr><td colspan="2">How to assess:</td></tr>
<tr><td colspan="2">Water allocation priorities exist in certain areas prone to water scarcity. For example, in some places, public water supply is regarded as more important than electricity cooling and the other way around. In turn, electricity cooling of sensible operations (e.g., nuclear plants) may have priority over irrigation. This prioritization scheme only sometimes exists and depends on the specific context. This indicator aims to assess the existence of such prioritization and whether or not the relevant stakeholders agree upon it.

The nature of the indicator implies that the results may change depending on the engaged stakeholders. For this reason, it is very important to account for representatives of all groups of interest when doing the assessment.</td></tr>
<tr><td colspan="2">How to use:</td></tr>
<tr><td colspan="2">The assessed indicator provides qualitative evidence on the existence of water allocation prioritization schemes, whether or not they are necessary, and if they are appropriate. However, the degree of consensus is critical to understanding if (dis)agreements are heterogeneous among stakeholders.</td></tr>
</table>

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

4. Conclusions and Next Steps

In this report, we have presented a monitoring framework for the assessment of indicators related to water governance. First, we explain the criteria for selecting these indicators and suggest a process for using them. Our framework incorporates the significant WEFE Nexus approach. Furthermore, for each indicator within the framework we highlight publicly available data to assess it. The second contribution is the consideration of indicators that allow assessing policy outcomes and impacts. In what follows, we describe the two main lessons from this exercise.

Lesson 1. Balance quantitative and qualitative indicators.

As described in section 2, a monitoring framework should be comprehensive of both quantitative and qualitative indicators. These two dimensions allow decision-makers and stakeholders to assess different aspects of the local water governance system. Specifically, quantitative measures are more appropriate for benchmarking and between-contexts comparisons. Qualitative aspects are fundamental to better understand the peculiarities of the water governance practices within the same context. It is therefore crucial that a proper balance is guaranteed between the two categories of indicators, to avoid the shortcomings of a partial approach.

Lesson 2. Data availability and scale.

For most of the indicators proposed in our framework, we are able to identify public databases and open data repositories. Nevertheless, this data often comes at a relatively broad aggregation scale (often the national level). The implication of this finding is that using public data, the assessment of the indicators within the proposed monitoring framework can be achieved up to a certain point. For detail, and better fit to the RETOUCH NEXUS case studies, an effort is needed to gather data at the local or case study level. This type of data is often not public and needs to be obtained through collaboration with key stakeholders. In some specific cases, data is available at a finer scale. The advantage of this case is that it allows assessment at multiple levels of aggregation, which allows for a more detailed analysis.

Next steps: calculating indicators for RETOUCH NEXUS case studies

Identify training material for the assessment of indicators

Given the need to calculate the indicators at the case study level, during the project's next steps, we will provide training material for assessing indicators within the case studies. This is especially important for the qualitative indicators for which data is unavailable. In this manner, the training material could be used in stakeholder engagement meetings. A promising approach to achieve this goal is provided in OECD (2022). A similar approach will be adapted for the RETOUCH NEXUS indicators.

Illustrate the process of indicator assessment with a real example.

We will demonstrate the assessment of indicators within the monitoring framework, using publicly available data at the national level for the RETOUCH NEXUS countries. This practical example will be a valuable tool in stakeholder engagement consultations, displaying the benefits of using qualitative and quantitative indicators.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

RETOUCH NEXUS

Apply framework to case studies.

Using the training material and the example described in the previous steps, we will apply the indicator framework to the RETOUCH NEXUS case studies.

Compile the results of the case study assessment.

RETOUCH NEXUS will use the assessment of the indicators within case studies for the development of T1.5: lessons learnt from indicators and monitoring framework. The objective is to provide guidelines to replicate the exercise more widely at the national level in the European Union.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

5. References

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao, Rome 300, D05109.

Arthur, Mercy; Liu, Gengyuan; Hao, Yan; Zhang, Lixiao; Liang, Sai; Asamoah, Ernest Frimpong; Lombardi, Ginevra Virginia (2019): Urban food-energy-water nexus indicators: A review. In Resources, Conservation and Recycling 151, p. 104481. DOI: 10.1016/j.resconrec.2019.104481.

Asian Development Bank (2020): Asian Water Development Outlook 2020: Description of Methodology and Data. Available online at https://www.adb.org/documents/awdo-2020-methodology-data.

Bastiaanssen, W.G.M., Molden, D.J., Makin, I.W., 2000. Remote sensing for irrigated agriculture: examples from research and possible applications. Agric Water Manag 46, 137–155.

Beillouin, Damien; Demenois, Julien; Cardinael, Rémi; Berre, David; Corbeels, Marc; Fallot, Abigail et al. (2022): A global database of land management, land-use change and climate change effects on soil organic carbon. In Scientific data 9 (1), p. 228. DOI: 10.1038/s41597-022-01318-1.

Bidoglio, G., Vanham, D., Bouraoui, F., & Barchiesi, S. (2019). The Water-Energy-Food-Ecosystems (WEFE) Nexus. In B. Fath (Ed.), Encyclopedia of Ecology (Second Edition) (pp. 459–466). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.11036-X

Burek, Peter; Satoh, Yusuke; Kahil, Taher; Tang, Ting; Greve, Peter; Smilovic, Mikhail et al. (2020): Development of the Community Water Model (CWatM v1.04) – a high-resolution hydrological model for global and regional assessment of integrated water resources management. In Geosci. Model Dev. 13 (7), pp. 3267–3298. DOI: 10.5194/gmd-13-3267-2020.

Cheng, Minghan; Jiao, Xiyun; Shi, Lei; Penuelas, Josep; Kumar, Lalit; Nie, Chenwei et al. (2022): High-resolution crop yield and water productivity dataset generated using random forest and remote sensing. In Scientific data 9 (1), p. 641. DOI: 10.1038/s41597-022-01761-0.

Damkjaer, Simon; Taylor, Richard (2017): The measurement of water scarcity: Defining a meaningful indicator. In Ambio 46 (5), pp. 513–531. DOI: 10.1007/s13280-017-0912-z.

Dillon, P., Arshad, M., 2016. Managed aquifer recharge in integrated water resource management. Integrated groundwater management: Concepts, approaches and challenges 435–452.

El-Gafy, Inas (2017): Water–food–energy nexus index: analysis of water–energy–food nexus of crop's production system applying the indicators approach. In Appl Water Sci 7 (6), pp. 2857–2868. DOI: 10.1007/s13201-017-0551-3.

European Environment Agency (2018): Water Exploitation Index plus (WEI+) at the river basin scale. Available online at https://www.eea.europa.eu/en/datahub/datahubitem-view/135a19fd-f799-44d7-bbd0-30ccade42553, updated on 5/8/2024, checked on 5/8/2024.

European Environment Agency (2021): WISE Water Framework Directive Database. Available online at https://www.eea.europa.eu/en/datahub/datahubitem-view/dc1b1cdf-5fa0-4535-8c89-10cc051e00db, updated on 5/23/2024, checked on 5/23/2024.

European Environment Agency (2023a): Corine Land Cover. Available online at https://www.eea.europa.eu/en/datahub/datahubitem-view/a5144888-ee2a-4e5d-a7b0-2bbf21656348, updated on 5/14/2024, checked on 5/14/2024.

European Environment Agency (2023b): Seasonal water scarcity conditions across Europe, measured by the water exploitation index plus (WEI+) for sub river basins, 2019. Available online at https://www.eea.europa.eu/data-and-maps/figures/seasonal-water-exploitation-index-plus-4, updated on 2023, checked on 5/8/2024.

European Environment Agency (2024): Water exploitation index, plus (WEI+) (2000-2019). Available online at https://www.eea.europa.eu/en/datahub/datahubitem-view/6c086807-f88f-4978-9823-c4b17bb52400, updated on 5/14/2024, checked on 5/14/2024.

Eurostat (2022): Water made available for use.

Eurostat (2024): Water exploitation index, plus (WEI+).

FAO (2024): AQUASTAT database.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Financing Water Supply, Sanitation and Flood Protection (2020): OECD.

Food and Agriculture Organisation of the United Nations (FAO) (2018): FAO Soils Portal – Global Soil Organic Carbon Map Technical Report. (section Technical Report, V1.2.0). Available online at https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/global-soil-organic-carbon-map-gsocmap/en/, updated on 5/21/2024, checked on 5/21/2024.

Food and Agriculture Organisation of the United Nations (FAO) (2024): FAO Soils Portal – Global Soil Organic Carbon Map (GSOCmap). (section GSOCmap Web Service). Available online at https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/global-soil-organic-carbon-map-gsocmap/en/, updated on 5/21/2024, checked on 5/21/2024.

Francesconi, W., Srinivasan, R., Pérez-Miñana, E., Willcock, S.P., Quintero, M., 2016. Using the Soil and Water Assessment Tool (SWAT) to model ecosystem services: A systematic review. J Hydrol (Amst) 535, 625–636.

Garcia-Prats, A., Carricondo-Antón, J.M., Jiménez-Bello, M.A., Juárez, J.M., López-Pérez, E., Pulido-Velazquez, M., 2023. Dynamic procedure for daily PM56 ETo mapping conducive to site-specific irrigation recommendations in areas covered by agricultural weather networks. Agric Water Manag 287, 108415.

Han; Y. Zeng; Lijie Zhang; Chao Wang; Egor Prikaziuk; Zhenguo Niu; Z Su (2023): Global long term daily 1km surface soil moisture dataset with physics informed machine learning.

Hoff, H. (2011). Understanding the Nexus. Background Paper for the Bonn2011 Conference: The Water, Energy and Food Security Nexus. Stockholm Environment Institute, Stockholm.

Jacobson, M., Meyer, F., Oia, I., Reddy, P., & Tropp, H. (2013). User's guide on assessing water governance. United Nations Development Programme, Oslo.

Jian, Jinshi; Du, Xuan; Stewart, Ryan D.; Tan, Zeli; Bond-Lamberty, Ben (2020): <i>SoilErosionDB</i>: A global database for surface runoff and soil erosion evaluation. In Earth System Science Data Discussions, pp. 1–22. DOI: 10.5194/essd-2020-283.

Karabulut, Armağan; Egoh, Benis N.; Lanzanova, Denis; Grizzetti, Bruna; Bidoglio, Giovanni; Pagliero, Liliana et al. (2016): Mapping water provisioning services to support the ecosystem–water–food–energy nexus in the Danube river basin. In Ecosystem Services 17, pp. 278–292. DOI: 10.1016/j.ecoser.2015.08.002.

Karnib, Ali (2018): Bridging Science and Policy in Water-Energy-Food Nexus: Using the Q-Nexus Model for Informing Policy Making. In Water Resour Manage 32 (15), pp. 4895–4909. DOI: 10.1007/s11269-018-2059-5.

Khan, Zarrar; Thompson, Isaac; Vernon, Chris R.; Graham, Neal T.; Wild, Thomas B.; Chen, Min (2023): Global monthly sectoral water use for 2010-2100 at 0.5° resolution across alternative futures. In Scientific data 10 (1), p. 201. DOI: 10.1038/s41597-023-02086-2.

Levintal, E., Kniffin, M.L., Ganot, Y., Marwaha, N., Murphy, N.P., Dahlke, H.E., 2023. Agricultural managed aquifer recharge (Ag-MAR)—a method for sustainable groundwater management: A review. Crit Rev Environ Sci Technol 53, 291–314.

Liu, J., Hull, V., Godfray, H. C. J., Tilman, D., Gleick, P., Hoff, H., Pahl-Wostl, C., Xu, Z., Chung, M. G., Sun, J., & Li, S. (2018). Nexus approaches to global sustainable development. Nature Sustainability, 1(9), Article 9. https://doi.org/10.1038/s41893-018-0135-8

Lorite, I.J., Mateos, L., Fereres, E., 2004. Evaluating irrigation performance in a Mediterranean environment: I. Model and general assessment of an irrigation scheme. Irrig Sci 23, 77–84.

MacAlister, Charlotte; Baggio, Guillaume; Perera, Duminda; Qadir, Manzoor; Taing, Lina; Smakhtin, Vladimir (Eds.) (2023): Global Water Security 2023 Assessment. United Nations University Insitute United Nations, University Institute for Water, Environment and Health. Hamilton, Canada. Available online at https://collections.unu.edu/view/UNU:9107#viewMetadata.

Mekonnen, M. M.; Hoekstra, A. Y. (2011): National water footprint accounts: the green, blue and grey water footprint of production and consumption. UNESCO-IHE. Delft, The Netherlands (Value of Water Research Report Series, 50).

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

RETOUCH NEXUS

Melloni, G., Dias-Turetta, A. P., Löhr, K., Bonatti, M., Sieber, S. (2022). A theoretical framework to address multi-level governance challenges. In Handbook on the Water-Energy-Food Nexus (pp. 346-363). Edward Elgar Publishing.

Ministry of Agriculture and Rural Development of the Slovak Republic (MARD) (2023): Water for Climate Healing: a new paradigm [White paper]. Available online at https://www.mpsr.sk/en/index.php?navID=54&id=84.

Molden, D., 2013. Water for food water for life: A comprehensive assessment of water management in agriculture. Routledge.

Muñoz-Sabater, J., Dutra, E., Agustí-Panareda, A., Albergel, C., Arduini, G., Balsamo, G., Boussetta, S., Choulga, M., Harrigan, S., Hersbach, H., 2021. ERA5-Land: a state-of-the-art global reanalysis dataset for land applications, Earth Syst. Sci. Data, 13, 4349–4383.

Muñoz-Sabater, Joaquín; Dutra, Emanuel; Agustí-Panareda, Anna; Albergel, Clément; Arduini, Gabriele; Balsamo, Gianpaolo et al. (2021): ERA5-Land: a state-of-the-art global reanalysis dataset for land applications. In Earth Syst. Sci. Data 13 (9), pp. 4349–4383. DOI: 10.5194/essd-13-4349-2021.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R., 2011. Soil and water assessment tool theoretical documentation version 2009. Texas Water Resources Institute.

OECD. (2015), OECD Principles on Water Governance, www.oecd.org/governance/oecd-principleson-water-governance.htm.

OECD. (2018). Implementing the OECD Principles on Water Governance: Indicator Framework and Evolving Practices, OECD Studies on Water, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264292659-en

OECD. (2022). How to assess water governance. OECD, Paris. https://web-archive.oecd.org/2022-06-24/627280-How_to_assess_water_governance.pdf

Pereira, A.R., Green, S., Nova, N.A.V., 2006. Penman–Monteith reference evapotranspiration adapted to estimate irrigated tree transpiration. Agric Water Manag 83, 153–161.

Pettorelli, N., 2019. Satellite remote sensing and the management of natural resources. Oxford University Press.

Pettorelli, Nathalie; Schulte to Bühne, Henrike; Tulloch, Ayesha; Dubois, Grégoire; Macinnis-Ng, Cate; Queirós, Ana M. et al. (2018): Satellite remote sensing of ecosystem functions: opportunities, challenges and way forward. In Remote Sens Ecol Conserv 4 (2), pp. 71–93. DOI: 10.1002/rse2.59.

Raes, D., Steduto, P., Hsiao, T.C., Fereres, E., 2009. AquaCrop—the FAO crop model to simulate yield response to water: II. Main algorithms and software description. Agron J 101, 438–447.

Rodell, M., Zaitchik, B.F., Li, B., Bolten, J.D., Houborg, R., Velicogna, I., Famiglietti, J.S., 2009. Hydrologic Applications of GRACE Terrestrial Water Storage Data, in: AGU Fall Meeting Abstracts. pp. G33E-05.

Scanlon, B.R., Healy, R.W., Cook, P.G., 2002. Choosing appropriate techniques for quantifying groundwater recharge. Hydrogeol J 10, 18–39. https://doi.org/10.1007/s10040-001-0176-2

Scanlon, B.R., Rateb, A., Pool, D.R., Sanford, W., Save, H., Sun, A., Long, D., Fuchs, B., 2021. Effects of climate and irrigation on GRACE-based estimates of water storage changes in major US aquifers. Environmental Research Letters 16, 094009.

Shukla, S., Wood, A.W., 2008. Use of a standardized runoff index for characterizing hydrologic drought. Geophys Res Lett 35.

Simpson, Gareth (2020): WEF Nexus Index dataset.

Simpson, Gareth B.; Jewitt, Graham P. W.; Becker, William; Badenhorst, Jessica; Masia, Sara; Neves, Ana R. et al. (2022): The Water-Energy-Food Nexus Index: A Tool to Support Integrated Resource Planning, Management and Security. In Front. Water 4, Article 825854. DOI: 10.3389/frwa.2022.825854.

Sood, A.; Nicol, A.; Arulingam, I. (2019): Unpacking the water-energy-environment-food nexus: working across systems.

Steduto, P., Hsiao, T.C., Fereres, E., Raes, D., 2012. Crop yield response to water. fao Rome.

Steduto, P., Hsiao, T.C., Raes, D., Fereres, E., 2009. AquaCrop—The FAO crop model to simulate yield response to water: I. Concepts and underlying principles. Agron J 101, 426–437.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.

Stettz, S., Heath, A., Li, B., Beaudoing, H., Rodell, M., 2022. A Visual Guide to the GRACE Data Assimilation for Drought Monitoring (GRACE-DA-DM) Data Products, in: AGU Fall Meeting 2022.

Turek, Maria Eliza; Poggio, Laura; Batjes, Niels H.; Armindo, Robson André; van Jong Lier, Quirijn de; Sousa, Luis de; Heuvelink, Gerard B.M. (2023): Global mapping of volumetric water retention at 100, 330 and 15 000 cm suction using the WoSIS database. In International Soil and Water Conservation Research 11 (2), pp. 225–239. DOI: 10.1016/j.iswcr.2022.08.001.

UNCCD Science-Policy Interface (2019): Tools for Soil Organic Carbon Estimation and Management: United Nations Convention to Combat Desertification. Available online at https://cgspace.cgiar.org/items/1281a67e-3540-4e3f-bc6f-49faa18d5620.

Vicente-Serrano, S.M., Beguería, S., Lorenzo-Lacruz, J., Camarero, J.J., López-Moreno, J.I., Azorin-Molina, C., Revuelto, J., Morán-Tejeda, E., Sanchez-Lorenzo, A., 2012. Performance of drought indices for ecological, agricultural, and hydrological applications. Earth Interact 16, 1–27.

Vicente-Serrano, S.M., Beguería, S., Lorenzo-Lacruz, J., Camarero, J.J., López-Moreno, J.I., Azorin-Molina, C., Revuelto, J., Morán-Tejeda, E., Sanchez-Lorenzo, A., 2012. Performance of drought indices for ecological, agricultural, and hydrological applications. Earth Interact 16, 1–27.

Virkki, Vili; Alanärä, Elina; Porkka, Miina; Ahopelto, Lauri; Gleeson, Tom; Mohan, Chinchu et al. (2022): Globally widespread and increasing violations of environmental flow envelopes. In Hydrol. Earth Syst. Sci. 26 (12), pp. 3315–3336. DOI: 10.5194/hess-26-3315-2022.

World Bank Open Data (2024): Water productivity, total (constant 2015 US$ GDP per cubic meter of total freshwater withdrawal). Available online at https://data.worldbank.org/indicator/ER.GDP.FWTL.M3.KD?end=2020&name_desc=false&start=1965&view=chart, updated on 5/14/2024, checked on 5/14/2024.

Wuepper, David; Borrelli, Pasquale; Finger, Robert (2020): Countries and the global rate of soil erosion. With assistance of David Johannes Wüpper: ETH Zurich (3). Available online at https://www.research-collection.ethz.ch/handle/20.500.11850/438015.

Xingcai Liu (2024): Global environmental flow requirement estimates based on multimodel simulations.

Zhang, Yonggen; Schaap, Marcel G.; Zha, Yuanyuan (2018): A High-Resolution Global Map of Soil Hydraulic Properties Produced by a Hierarchical Parameterization of a Physically Based Water Retention Model. In Water Resources Research 54 (12), pp. 9774–9790. DOI: 10.1029/2018WR023539.

Zhao, Rongqin; Liu, Ying; Tian, Mengmeng; Ding, Minglei; Cao, Lianhai; Zhang, Zhanping et al. (2018): Impacts of water and land resources exploitation on agricultural carbon emissions: The water-land-energy-carbon nexus. In Land Use Policy 72, pp. 480–492. DOI: 10.1016/j.landusepol.2017.12.029.

Zwart, S.J., Bastiaanssen, W.G.M., 2004. Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. Agric Water Manag 69, 115–133.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.