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Co-creating water knowledge: a community perspective

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Co-creating water knowledge: a community perspective

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ABSTRACT

Navigating the complexities of global and local water resources challenges requires collaboration and mutual learning among diverse knowledge systems and disciplines. However, Western philosophical approaches to generating knowledge have prevailed in water management and hydrology, often overlooking community priorities, practices and perspectives, and power asymmetries - including gender inequalities, racism, and colonial injustices. In this perspective paper, we explore the co-creation of water knowledge (CCWK) concept to value multiple and diverse forms of knowledge. We identify four overarching principles (inclusivity, openness, legitimacy, and actionability), highlighting the importance of establishing relationships and collaborative leadership, adopting key tools and techniques, and integrating knowledge for water resources management. Furthermore, we argue that prioritizing epistemic justice is essential for effective CCWK. To address these, we advocate for more interdisciplinary and reflexive research practices that challenge and disrupt Western scientific traditions shaped by functionalist and colonial legacies.

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1 Introduction

Equitable, efficient, and sustainable management of water resources and services is essential for human societies (Higgs *et al.* 2025). Today, many regions globally face water-related challenges, such as freshwater ecosystems and biodiversity collapse, declining water quality and quantity, increasing risk of floods and droughts, water insecurity, and inadequate access to water and sanitation services (Falkenmark *et al.* 2019, Grafton *et al.* 2025). Such challenges are further compounded by concerns about water injustices, as the negative impacts are unevenly experienced across different regions (e.g. upstream and downstream), between urban and rural populations, and among various social identities, including race and gender (Boelens *et al.* 2018, Sultana 2018, Rusca *et al.* 2023, Savelli *et al.* 2023). As water-related biophysical and socioeconomic processes are deeply interconnected, changes in hydrological systems influence socioecological and climate systems across multiple scales and vice versa, directly impacting human water needs and availability (Falkenmark 2017). As climate change impacts intensify and populations increase, the ability of societies to manage water resources sustainably is increasingly strained. National borders do not confine these issues; they affect continents, countries, and communities to varying degrees, and are influenced by a complex interplay of geographical, climatological, political, and socioeconomic factors (De Stefano *et al.* 2017, PosadaMarin *et al.* 2024). Hence, finding novel ways to promote and achieve equitable, efficient and sustainable management of water resources and services is essential (Higgs *et al.* 2025).

Consequently, hydrological science has become more concerned with generating knowledge to inform actions and solutions. One remarkable advancement is the introduction of "sociohydrology" (Sivapalan *et al.* 2012, Di Baldassare *et al.* 2019, Pande *et al.* in press), namely the study of the coevolution of society and water, accounting for the multiple dynamic feedbacks between the natural, technical, and social dimensions of human–water systems. Although sociohydrology recognizes the need to integrate more qualitative methods and sources of knowledge, it does not require a participatory approach during this process (Wesselink *et al.* 2017, Ross and Cheung 2020). A recent review estimated that only one third of sociohydrological studies involved stakeholders to generate knowledge (Vanelli *et al.* 2022).

This may result in further supporting the already dominant approach of knowledge generation in hydrology, centred on a researcher-led empirical scientific method based on hypothesis testing and inductive reasoning (Vanelli *et al.* 2022). Furthermore, the uptake of such knowledge into actions has been relatively limited, especially on the local scale. Such a knowledge generation process has often been criticized for overlooking the priorities, perspectives, and uneven power relations of those directly affected, leading to ineffectual, inequitable, and inconspicuous outcomes (Budds 2009).

Knowledge co-creation has been increasingly proposed as a core approach to fostering equitable and sustainable development (Jasanoff 2004, Krueger *et al.* 2016, Escobar 2018, Mitlin *et al.* 2020, Rusca *et al.* 2024). This is particularly relevant to the management of water resources and services (Mauser *et al.* 2013, MartinHill *et al.* 2022, Dupuits *et al.* 2023, Souza *et al.* 2024). Knowledge co-creation entails a wide array of practices and tools through which different actors collaborate to jointly understand, document, and, in some cases, address water-related challenges (Krueger *et al.* 2016, Hakkarainen *et al.* 2022). Such approaches have been suggested as "indispensable for understanding the multifaceted issues surrounding water" (Krueger *et al.* 2016, 370). Moreover, co-creation has been advanced as a way to challenge and move beyond Western scientific traditions shaped by functionalist and colonial legacies that still characterize water management and governance (Diver *et al.* 2019). Co-creation entails actively engaging with the plural ways of relating and knowing water held by diverse actors across society (Krueger *et al.* 2016, Acharya and Prakash 2019, Roque *et al.* 2022, Rusca *et al.* 2024). It can help to redress epistemic injustices and contribute to efforts to deconstruct Western scientific traditions and decolonize academia (Stein *et al.* 2024). Furthermore, recent research has shown that involving a wide range of social actors – including governments, scientific institutions, communities, grassroots movements and their different forms of water knowledge – can improve understanding of local water systems (Castelli *et al.* 2021, Nobrega *et al.* 2023, Sodoge *et al.* 2024). Knowledge co-creation can also lead to more effective solutions that address environmental and social challenges related to water resources (Mauser *et al.* 2013, MartinHill *et al.* 2022, Dupuits *et al.* 2023, Souza *et al.* 2024). For instance, in areas where conventional water management practices have struggled to address water scarcity, co-creation can lead to the generation and adoption of more innovative, cost-effective, or locally tailored solutions such as rainwater harvesting or community-based water management systems, which are often more sustainable and resilient (Castelli *et al.* 2018).

Despite its potential, the co-creation of water knowledge (CCWK) remains underutilized in hydrological science and water resources management. To date, specific research in the field has focused on (i) theories, methods and practices for knowledge co-creation; (ii) the challenges associated with co-creating water knowledge, including power asymmetries among knowledge holders; (iii) the inclusion of marginalized actors; (iv) the recognition of community heterogeneity; and (v) the methodological challenges of aligning scientific water research with community water management and needs (Krueger *et al.* 2016, Bou Nassar *et al.* 2021, T.D.G. Hermans *et al.* 2022).

In this context, the International Association of Hydrological Sciences (IAHS) has dedicated its current scientific decade (2023–2032) to providing Science for Solutions, namely: "*HELPING – Hydrology Engaging Local People IN one Global world*" (Arheimer *et al.* 2024). Among the research goals established for HELPING, the creation of new knowledge, inclusive of diverse perspectives and epistemological approaches, is represented in the objective of "Co-creating hydrological knowledge between people and between disciplines." In doing so, the aim of the decade is to broaden perspective and accelerate knowledge sharing, leading to more equitable and just solutions (Arheimer *et al.* 2024).

Within the HELPING decade, the Working Group on "Co-Creating Water Knowledge (CCWK)"[1] aims, among other goals, to "increase awareness in the hydrological community of the value of multiple and diverse water knowledge combinations for sustainable development in a changing world" (IAHS HELPING WG CCWK 2024). This perspective paper was written by the CCWK Working Group, an interdisciplinary group based and working across the globe. The group of authors includes researchers and practitioners working on water science with multi-, inter-, and transdisciplinary approaches, starting from various epistemological domains, including hydrology, geography, and social sciences. We bring together diverse experiences and approaches in terms of knowledge co-creation, including participatory research and interdisciplinary engagements (IAHS HELPING WG CCWK 2024). To further advance the adoption of CCWK, among a target audience of researchers and water experts, due to the scope of the journal and of IAHS, this joint paper aims to:

- Contextualize CCWK in relation to hydrological science (section 2.1) and analyse different definitions, interpretations, methodological approaches and applications (2.2);
- Set a foundation of overarching principles to guide co-creation processes in the context of hydrology (3.1);
- Identify and underscore key processes that shape the CCWK (3.2);
- Present case studies of CCWK, highlighting lessons learned (Boxes 1–5);
- Highlight practical, fundamental and far-reaching challenges in co-creating water knowledge that hold a critical lens to previous sections, discuss ways to overcome them, and set a research agenda. Based on the above-named challenges, project funding (4.1), power dynamics (4.2), operationalizing (4.3) and institutionalizing (4.4) this work, and overcoming epistemic justice (4.5), we outline our vision for future research on CCWK.

2 Navigating co-creation

2.1 The development of co-creation

Knowledge co-creation has evolved theoretically and practically across various fields, with contributions from different sectors and academic disciplines. In the business lexicon, co-creation refers to the "joint production of value" between customers and firms through interactive processes (Lusch *et al.* 2007). In this context, co-creation emerged as a response to shifting consumer behaviour, increased competition, and the rise of digital technologies (Brandsen *et al.* 2018). In the public sector, co-creation – often used as a synonym of co-production – is widely applied, including in healthcare provision and education (Voorberg *et al.* 2015, Audia *et al.* 2021). For example, co-creation is used in education as a process where teachers become colearners and students move from passive recipients to active cocreators of knowledge, which involves a nonhierarchical relationship, flexible curriculum, and reflexive assessment practices (Vespestad and Smørvik 2019, Kaminskienė *et al.* 2020).

In the academic research context, the meaning of co-creation shifts to reflect different disciplinary dynamics. It broadly refers to collaborative processes in which diverse actors, including local communities, academia, policymakers and practitioners, jointly generate knowledge. In anthropology, for instance, co-creation is often used interchangeably with co-production and codesign (Escobar 2018). In current debates on the decolonization of academic research, co-creation is primarily used for the design of and experimentation with new collaborative methods in order to avoid cognitive (Santos 2015) or epistemic injustices (Kidd *et al.* 2017), proposed as part of efforts to account for and engage with a plurality of perspectives, practices and knowledges.

In environmental research, co-creation includes diverse approaches and aims, such as arts-based initiatives with various actors (HoTassone *et al.* 2023, Gianelli *et al.* 2024, Hamamouche *et al.* 2024) and citizen science frameworks of early warning systems (Marchezini *et al.* 2018). Within water resources management and hydrology, co-creation has included the development of strategies, policies, and measures

[1] https://iahs.info/Initiatives/Scientific-Decades/helping-working-groups/co-creating-water-knowledge/

to manage flood and drought risk, poor water quality, freshwater allocation, and transboundary river management (Thaler *et al.* 2021). For instance, co-creation enabled the development of river basin management plans (Graversgaard *et al.* 2017) and the creation of a framework for assessing the impact of drought (De Angeli *et al.* 2025).

2.2 Co-creation and co-production

Despite its diverse applications and widespread use, there is a lack of consensus on a clear conceptualization of what co-creation is and how it should be used (Wehbe *et al.* 2024). Co-creation is often used interchangeably with co-production and codesign. These concepts are deeply rooted in transdisciplinary research, which involves researchers and nonacademic actors who work together as equal partners to address complex issues, and integrate diverse knowledge systems and perspectives (Wibeck *et al.* 2022).

A few distinctive features of co-creation are ubiquitous, such as the joint creation of value for all participants (Leclercq *et al.* 2016), multi-actor engagement (Jones 2018), and a focus on innovation and problem solving (Brandsen *et al.* 2018).

Co-production is also a travelling concept whose origin is difficult to place because it has developed simultaneously across different academic communities. Some authors place the origins of these concepts in the early 1970s in the public sector and the development of public safety services, also popularized in the work of scholars such as Elinor Ostrom and other economists who studied collaboration between public departments and citizens (Ostrom 1996). At the same time, it has developed simultaneously across different academic communities, including public administration (Ostrom 1996); science and technology studies (STS; stemming from the work of Sheila Jasanoff 2004); and sustainability science (BandolaGill *et al.* 2023).

There are major similarities and overlaps between co-creation and co-production. For example, both aim for broad participation (Brandsen *et al.* 2018), involve knowledge exchange and colearning, and can lead to innovative solutions and policy change towards sustainability (Norstrom *et al.* 2020). The concepts are often hard to distinguish; for example, forms of co-production resemble what value-based co-creation initiatives pursue, such as "co-production as transdisciplinarity" identified by BandolaGill *et al.* (2023) or the "researching solution" mode of co-production found by Chambers *et al.* (2021). Some frameworks integrate the terms, most commonly where co-creation is positioned as a step of a larger co-production framework (Mauser *et al.* 2013, Audia *et al.* 2021, Hakkarainen *et al.* 2022, De Angeli *et al.* 2025).

With the increasing use of the terms co-production and co-creation across varied contexts, multiple definitions tailored to the requirements and nuances of different disciplines, actors, and challenges continue to emerge. Even within our working group, with members from different disciplines working on water-related and sustainability science problems, we experienced considerable debate on how to define co-creation. Among others, we find the distinction Brandsen and Honingh (2018) suggested useful.

Focusing on the context of public service provision, they argue that the term co-creation differs from co-production in terms of the stage of involvement. Co-production includes the participation of citizens exclusively in the product or service delivery or implementation phase and not in the idea or design process. Co-creation, conversely, focuses on the strategic or initial phases, such as planning, designing, or initiating public services. The collaboration here starts and takes place in the early stages, preferably from the beginning (Brandsen and Honingh 2018), focusing more on creative methods (Haviland 2017). Even if it should be considered that in some references, co-production is used to define processes starting in the early stages (Audia *et al.* 2021, O'Connor *et al.* 2021), the framework by Brandsen and Honingh (2018) is also supported by other scholars, such as Hakkarainen *et al.* (2022), who traced back the epistemological roots of co-creation to Latour (1988). According to their interpretation, co-creation represents one of the new forms of knowledge production to address change, uncertainty, and transformative goals. Rather than providing solutions, it contributes to identifying and developing solution options (Wiek *et al.* 2015), focusing on "a deeper thinking which in itself is essential for a transition towards a world that is more sustainable" (Wals and Rodela 2014, p. 1).

Focusing more on the initial phases of the conceptualization of a problem, co-creation offers the potential for integrating marginalized groups, including Indigenous communities, and their water knowledge based on different (water) ontologies in the very initial phases of a process.

For the scope of the present paper, we identify in the framing by Brandsen and Honingh (2018) a useful distinction between the approaches. Hereinafter, we refer to co-creation as a collaborative process that is more focused on an iterative interaction leading to new knowledge – e.g. a new understanding of a problem – where collaboration is essential from the strategic or initial phases of the process (Roux *et al.* 2010, Bremer and Meisch 2017). In contrast, we consider co-production rather focused on creating specific, practical outputs (e.g. to create a service or a product) through a more structured collaboration that may happen in different stages of a process (Lemos *et al.* 2018, Oliver *et al.* 2019). Thus, we adopt the definition of the first for CCWK, as a form of collaboration centred on (a) water-related management challenge(s) and/or hydrological question(s) that integrates different forms and origins of knowledge right from the start.

3 Co-creation approaches in hydrological science and water resources management

This section presents a set of overarching principles that can support a successful knowledge co-creation process in hydrological science and water resources management. This is followed by a selection of co-creation approaches that shape the process, drawn from our collective experiences and perspectives. The section was elaborated during multiple consecutive meetings held by the authors within the CCWK working group. During the meetings, several members highlighted their experiences and ideas about principles and approaches to co-creation, supported by experiences (case studies) and references. With the support of case study examples (boxes), we aim to make our reflection more tangible and thus lay the foundation for our vision without creating rigid guidelines precluded by inherent context dependencies. In addition, we aim to establish a reference baseline for the HELPING decade in 2032, when we hope to share more comprehensive and specific experiences and guidance based on an extensive database of our co-creation experiences according to the perspective delivered here. These principles and processes are drawn from existing frameworks in related disciplines with histories of publishing about co-creation, but by writing them here, we are proposing them as a distinct assembly relevant for water, ranging from water resource management and policy to hydrological science.

3.1 Overarching principles

While acknowledging that the process of CCWK must be case specific, we outline four overarching principles that, we believe, are fundamental to every step of any co-creation process related to water resources management and hydrology: inclusivity, openness, legitimacy, and actionability. These principles are strongly informed by our own experiences and beliefs, by current academic literature on co-creation (e.g. Gawler 2002, Mackenzie *et al.* 2012), and by data-sharing principles (Cudennec *et al.* 2020, 2022a), such as the Collective Benefit, Authority to Control, Responsibility, and Ethic (CARE) principles for Indigenous data governance (Carroll *et al.* 2020, 2021, Riedel *et al.* 2020). Although such principles are general and relevant for many disciplines and applications, they are particularly important for water management and hydrological science, which are cross-cutting by nature and fundamental to almost all natural and societal domains.

(1) **Inclusivity**: This principle strives to ensure that all actors involved or affected are represented and acknowledged, and benefit from the co-creation process equitably, while emphasizing mutual respect and diverse ways of knowing, thus overcoming barriers to vocalizing and listening. It highlights the importance of recognizing, reflecting on, and addressing inequalities – especially uneven power relations between people involved in co-creation processes – and valuing all perspectives equally (Gawler 2002, Carroll *et al.* 2020, Cudennec *et al.* 2022a, 2022b). As it is expressed in the present paper, the principle of "inclusivity" does not reflect the need to include all actors, as some actors can choose not to be involved, or to be involved with different dynamics or processes, to overcome power imbalances (Cleaver 1999, Butler and Adamowski 2015, Biancardi Aleu *et al.* 2022).

(2) **Openness**: This principle emphasizes the need to foster an open, trustworthy, transparent, respectful, encouraging, and creative atmosphere that is receptive to a range of practices of knowing and thinking, from modelling to sensing or feeling (FalsBorda 2015, Baciurin *et al.* 2023, Nóbrega *et al.* 2023, Souza *et al.* 2024). As an example, feelings are a form of communication, and by paying attention to the emotional response they convey, researchers can be prompted to address underlying concerns constructively (Jiang *et al.* 2016, RestrepoEstrada *et al.* 2018, Li and Reynolds 2021, Baciurin *et al.* 2023). Additionally, it stresses the importance of maintaining transparency throughout the co-creation process, such as when making decisions and setting expectations. Open communication is a vital prerequisite of this process, allowing multiple actors to communicate and collaborate without central control (e.g. Box 1, and resonating with the first principle of open hydrology; see Dogulu *et al.* 2024). The openness principle also encompasses the need to be flexible by adjusting research objectives, timelines, and methods to evolving circumstances and priorities (LotzSisitka and Burt 2006, Mackenzie *et al.* 2012). In any case, the "openness" principle should not be interpreted as a call to open communication at any cost, but rather as a reflection on how to valorize and respect all forms of communication and noncommunication. For example, some traditional information, especially when dealing with Indigenous knowledge systems, can be protected and not shared (Masoni 2017).

(3) **Legitimacy**: This principle stresses the importance of ensuring local communities', marginalized groups', or other nonacademic actors' representation and involvement as equal participants throughout the co-creation process (Wilk and Johnston 2013, Carroll *et al.* 2020) and collaboratively defining research aims, questions, methodologies, and solutions accordingly. It also strives towards balancing power dynamics among actors, ensuring fair participation and decision making for all parties. Respecting this principle means that the researchers' roles and positions are clear and agreed upon from the beginning, although they may evolve (e.g. servant leadership in Box 4; Mackenzie *et al.* 2012). To facilitate this evolution, a research timeline could include milestones dedicated to reflecting on the changing positionalities of researchers and nonacademic participants throughout the process.

(4) **Actionability**: This principle highlights the importance of using appropriate technologies and tools that enhance water science in a way that is usable, useful, and used (Jagannathan *et al.* 2023, Zanetta 2025; Box 4). This includes using models, terminology, symbology, and multifunctional approaches to represent water knowledge that are understandable and relatable to all actors. This might entail the creation of environmental observatories (Karpouzoglou *et al.* 2015) to ensure long-term measurement of key meaningful variables that are relevant, accessible, and usable by the entire community, helping to establish a connection with local people and encouraging their participation in the monitoring process (OchoaTocachi *et al.* 2018). Furthermore, this principle promotes knowledge exchange and capacity building, ensuring lasting benefits for local communities (Gawler 2002, Mackenzie *et al.* 2012).

Box 1. Case study - Living Dikes: nature-based flood protection in the Netherlands

The Netherlands has a long history of co-creating knowledge and shaping land and waterscapes, primarily for flood protection (Vreugdenhil *et al*. 2022). This heritage has led to innovative approaches like "living dikes," a nature-based solution that combines traditional 'hard' infrastructure with 'soft' natural elements to provide flood protection and environmental benefits (TU-Delft 2023).

Building on earlier projects, a consortium of scientists and practitioners has been working to develop further the concept of living dikes (U-Today 2024). Funded by the Dutch National Science Council (NWO) and societal partners like the regional water authority of Fryslan, this large-scale project includes research on governance, hydroecology, and water resources under environmental change, as well as practical challenges of implementing and scaling nature-based flood solutions.

Inclusivity and diversity were central to establishing the co-creation team, including scientists, local communities, and civil water authorities, leveraging existing connections and combining new and existing collaborations. These actors were meaningfully included using a cooperation instrument (Co-Add) based on participatory game theory and policy analysis (Vreugdenhil *et al*. 2022). Co-Add helped actors identify shared opportunities and synergies and helped them realise which solutions were achievable and what was needed to enable implementation, including their own contributions.

Engaging a range of actors ensured the integration of various perspectives into the project design and implementation and balanced scientific insights with local needs. New information, insights, and outcomes from multiple project streams (e.g., research and governance) were shared regularly with the co-creation team to foster transparency and build trust, allowing the project to integrate feedback dynamically.

Beyond the project team, other affected parties (e.g., experts from water authorities and local government) were frequently engaged in a collaborative approach that improved the legitimacy of the project and the acceptability of outcomes. It also ensured that the project objectives reflected the realities of the community and aligned with the local needs for sustainable flood protection. Adopting such an approach improved the actionability of outcomes, enabling research findings to be used directly to make decisions, for example, informing the design of the living dikes (Figure 1).

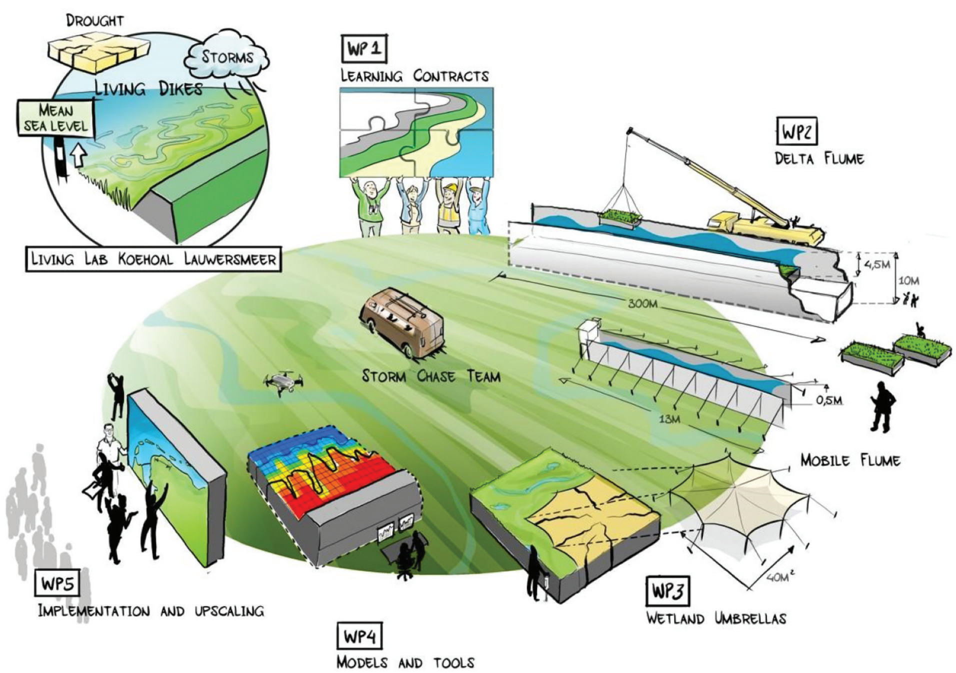

Figure 1. Artist's impression of the challenges addressed and the structure of the Living Dikes project. WP = work package. Image credit: Joost Fluitsma for Living Dikes project.

3.2 Shaping the co-creation process

Building on the abovementioned overarching principles, the following paragraphs describe four key elements of a CCWK process: initiating and sustaining relationships, collaborative leadership, key tools and techniques, and knowledge inclusion. These elements are not designed to provide a sequence of steps to operationalize co-creation, available elsewhere in the literature (e.g. L.M. Hermans *et al*. 2022, Dushkova and Kuhlicke 2024). Here, we illustrate these implementation steps as a cyclical process, passing through all the key elements multiple times, in no particular order, highlighting the iterative nature of co-creation defined by the overarching principles and key elements but adapted to each specific context. We visualize the CCWK process as unfolding within a space defined by the four overarching principles (i.e. inclusivity, openness, legitimacy, and actionability), where the key elements evolve along this iterative implementation spiral (Fig. 2). We visualize these key elements as water drops that travel and reemerge through the steps, analogous to how water travels through the physical environment; just as a water drop never leaves the cycle, a process that initiates co-creation will reoccur as those relationships develop. These processes are particularly relevant for the water sector because of its conflicting legacy – on one hand establishing itself as a science during the age of enlightenment and on the other hand drawing heavily on concepts developed independently in most major epistemological traditions (Beven *et al*. 2025) – despite also being a ubiquitous subject of common knowledge. In

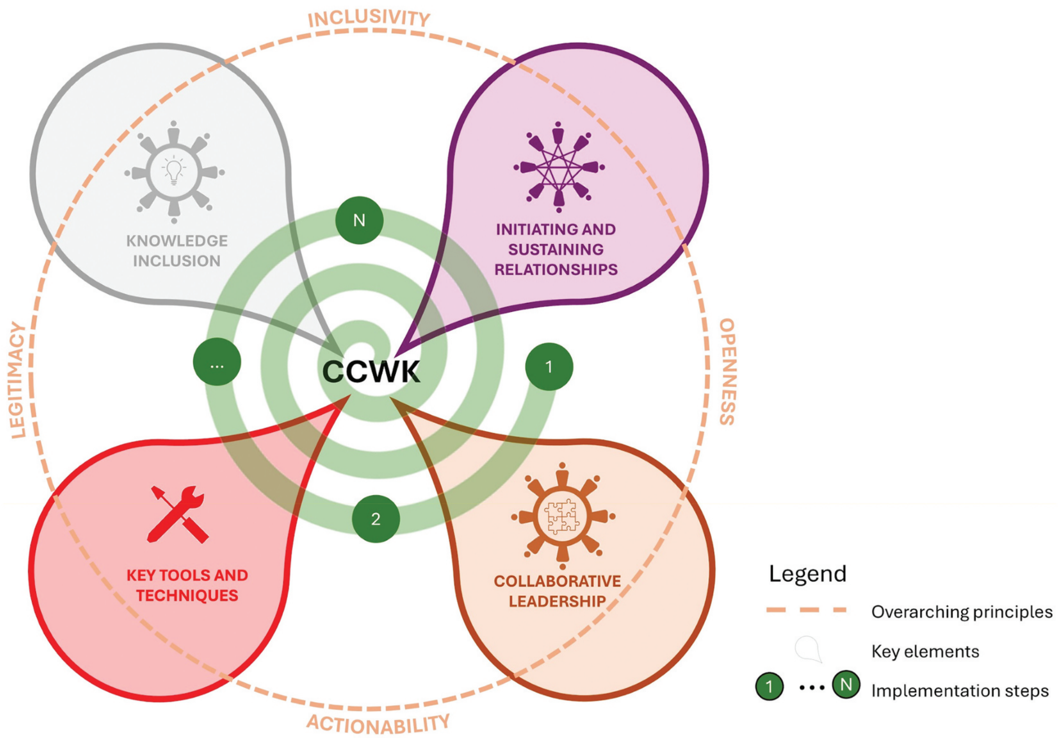

Figure 2. Overview of the Co-Creation of Water Knowledge (CCWK) encircled by overarching principles (openness, legitimacy, inclusivity, and actionability, shown by the orange dashed line), evolving along an iterative implementation spiral (shown in green, the number and nature of steps defined by the specific context), and consisting of approaches falling into four key cornerstone elements that transcend the steps and principles, visualized here as four water droplets highlighting the importance of initiating and sustaining relationships (purple), collaborative leadership (orange), key tools and techniques (red), and knowledge inclusion (grey).

addition, water, and its observation and documentation, is often the object of tension between the local and the centralized, with a historical tendency to centralize data and knowledge about water in regional and national government agencies, such that the local knowledge of a location's idiosyncrasies is lost (Beven *et al.* 2025). Overcoming these historical patterns and tendencies requires intentional processes designed along the overarching principles.

3.2.1 Initiating and sustaining relationships

Building sustainable, meaningful relationships with diverse collaborators is crucial for CCWK. Effective CCWK teams may evolve over multiple research projects or cycles (Fig. 2), affording opportunities to demonstrate commitment to shared objectives while fostering mutual understanding and respect for each other's concerns and priorities (Pohl *et al.* 2021). In water-related contexts – where environmental, political, and technical dimensions are tightly interconnected – these relationships support the integration of disciplinary, local, and experiential knowledge systems into coherent, actionable outcomes. Even if most of the relationship-building process occurs near the beginning of a CCWK process, it must be continually sustained, with existing and new collaborators engaged or reengaged throughout. Maintaining flexibility as research questions, objectives, and relationships evolve will keep the collaboration focused and relevant (Reed *et al.* 2018, Evers *et al.* 2025). Therefore, investing in relationships and agreeing on shared principles and expectations early in the process is important and worthwhile (Box 2). At the same time, meaningful co-creation processes should avoid overconsultation and participants' fatigue (Casal–Ribeiro *et al.* 2024), especially with marginalized groups or actors who often have less time to participate.

In general, CCWK begins by identifying and engaging with various actors who can contribute to or will be affected by the research process or outcomes. Researchers are encouraged to embrace the overarching principles from the start to successfully take an inclusive and open approach to identifying different interests, expertise, influences, and knowledge systems, thus encouraging the other actors. Accordingly, underrepresented perspectives and marginalized groups should be actively invited to ensure that all viewpoints, including those often overlooked, are represented (Gawler 2002, Carroll *et al.* 2020). The scope of involvement – who is involved, why, how, and where engagement occurs – needs to be carefully considered and communicated unambiguously in a first step by the initial CCWK team, and can be subject to iterative adjustments and negotiation (Lang *et al.* 2012). After initiating a new CCWK team, it may be necessary to continually encourage new collaborators to become involved as they are identified, for example, through a snowball recruitment strategy (Howard *et al.* 2024). In water-sector collaborations, this means identifying not only obvious institutional and community stakeholders but also those whose contributions are often missed, such as informal water users, traditional water managers, or seasonal actors whose participation may be essential at certain points in the hydrological cycle. Moreover, also including actors from other livelihood sectors, such as midwife

Box 2. Case study - Floating treatment wetlands system for urban water pollution remediation in Bangladesh, India, and Nepal

This project aimed to generate knowledge on the distribution and impacts of urban water pollution and the remediation potential of nature-based solutions, to implement new expertise through nature-based interventions, and to develop local water management capacity (The Small Earth Nepal 2021).
The Small Earth Nepal Nepal, an NGO and advocacy group, was foundational in establishing the co-creation team, including community groups, universities in Asia and the US, local municipalities, and other NGOs. The Small Earth Nepal leveraged its extensive networks to identify partners through community engagement activities, consultation with local authorities, and based on existing connections. Effective collaboration was kickstarted by a foundation of trust provided by many collaborators who had positive experiences working together.
The project was initiated through a series of workshops in which communities identified water pollution as a priority issue. The concept of floating treatment wetlands was introduced during training workshops. Participants were involved in designing, implementing, and maintaining the floating treatment wetlands and monitoring pre- and post-installation (e.g., by collecting water samples).
Local community leaders and key partners in the co-creation team provided insights into existing power dynamics and social structures, which allowed the project governance to be designed to enable equitable power sharing (Figure 3). For example, women and youth groups in Nepal were engaged in separate activities with smaller group sizes, to allow focussed discussion without overshadowing by more dominant voices (The Small Earth Nepal 2022, 2023). Local partners also provided insights on seasonal water flows, pollution sources, and traditional water management practices. Information from these discussions (e.g., concerns about the impacts on freshwater availability) were incorporated into the operational designs of the wetlands, which were ultimately decided upon by communities, helping to foster equitable power sharing and a sense of ownership. Spanning several countries, peoples, cultures, and languages, diversity and inclusivity were at the heart of the project. Activities were always conducted in the local language and dialect, often facilitated by local partners, except for international academic workshops in English. Materials from the project were shared in multiple languages and media e.g., community radio programs were broadcast in multiple languages to ensure everyone involved could access them.

Figure 3. (a) Agrometeorological Information Interpretation and Participant Feedback and Results Dissemination Workshops at Jumla and Bardiya. (b) The Small Earth Nepal team and Nagdaha Youth Club planting plants in the Floating Treatment Wetland System (FTWS) raft. (c) Onsite interaction meeting with the community radio broadcasters for a radio programme on the FTWS. (d) Tying the anchor on an FTWS Raft. Image credits: The Small Earth Nepal.

associations, health officers, etc., to account for cascading effects could be necessary. Ensuring their inclusion can improve the legitimacy and success of the co-creation process. By focusing on diverse perspectives, the CCWK process can enrich comprehension of water's (and its associated challenges') interconnected environmental, political, and technical aspects.

A diversity of expectations, aims, and objectives often accompanies diverse perspectives. Therefore, early in the CCWK process, it is crucial to understand each other's aims and to codefine research problems that are contextually relevant and whose solutions could be beneficial (Box 2; Norström *et al.* 2020, Dushkova and Kuhlicke 2024). This approach helps focus the process on the salience of outcomes, for example by enhancing the development of joint solutions and thus their actionability, acceptability, and adoption, which, in turn, limits scientific speculation. In this way, each participant can have the opportunity to preserve their identity while contributing to the process as a whole, including achieving shared goals.

Ideally, in a CCWK process, all participants play active roles, from defining research questions and selecting methods to interpreting data and disseminating (clearly defined) outcomes. Formal (e.g. memorandums of understanding or contracts) or informal (e.g. verbal commitments or handshakes) agreements may support outlining roles and activities while fostering accountability and demonstrating a long-term commitment to a group and a shared goal. In water governance settings, such agreements can clarify responsibilities in data sharing, safeguard intellectual property rights related to traditional water knowledge, and ensure continuity in monitoring and management even if personnel or political contexts change.

Given the typical diversity contained in CCWK teams, all cultural, socioeconomic (i.e. class, hierarchy, gender, age, income), and linguistic diversity should be considered thoughtfully throughout the process. For example, establishing shared terminology grounded in local languages and knowledge systems can bridge gaps between academic and nonacademic actors (Box 2; Tengö *et al.* 2017, Castelli *et al.* 2018, Hill *et al.* 2020, Norström *et al.* 2020, Reed *et al.* 2024). Addressing intergenerational differences is equally important, as elders and youth often bring distinct, complementary strengths that can be harnessed for more holistic outcomes (Pacetti *et al.* 2020, Gachuiri *et al.* 2022). Identifying logistical, economic, and skill-based constraints early on ensures that the co-creation process is feasible and not disproportionately laboursome or stressful for some parties, ensuring equitable contributions and that participants remain committed and motivated. In water projects, these relationship challenges can be compounded by the seasonality of water activities and use, the urgency of problems such as droughts and floods, and complex social contexts surrounding water management decisions, making the organization of engagement around these constraints critical for success. Planning and creating time for exchanges is a strategy to address challenges or misunderstandings and learn from mistakes. Building and maintaining relationships is a hard process that often involves mistakes, misunderstandings, and failure, but a resilient research process will learn and evolve from those experiences.

Understanding the dynamics and expectations within CCWK relationships is vital for reducing conflicts, especially when navigating different identities and thought collectives, including complex histories and/or cultural differences. Exploring and familiarizing oneself with participants' unique ways of knowing, communication styles, expectations, and belief systems will strengthen the inclusiveness of the co-creation process. It is essential to recognize existing hierarchies and power relations, particularly when vulnerable groups are involved, as these dynamics can impact participation and openness, potentially stifling honest dialogue and perpetuating existing inequities (Thaler and LevinKeitel 2016). Carefully moderating dominant individuals and creating a safe space for dialogue fosters open, honest communication, builds trust, and ensures that all participants feel secure and valued. Encouraging, and guiding reflection about the co-creation process, e.g. through dedicated sessions and tools, can allow for understanding how different actors feel included and understood during the research. In the water sector, these reflective and reflexive processes could, for example, uncover mismatches between scientific definitions of water scarcity and community perceptions, enabling adjustments that improve both relevance and trust in proposed interventions. At the same time, we cannot deny the political nature of many participatory (including co-creation) processes. In highly contested political arenas, forcing a co-creation process might even exacerbate political tensions and power imbalances which could be otherwise avoided (Calderon 2020).

3.2.2 Collaborative leadership

Effective co-creation often entails extensive dialogue and iteration among directly involved actors, researchers, and others with a stake in the project. In these contexts, leadership, guidance, and collaboration play a crucial role in fostering compromise and agreement – and yet it is not always easy to engage with the diversity of experiences, approaches, and normative commitments (Caniglia *et al.* 2023). How to forge leadership and collaboration skills to guide knowledge co-creation has been discussed and debated in sustainability science (Gordon *et al.* 2019). Among others, Schwartz and Sharpe (2010, as cited by Caniglia *et al.*, 2023, p. 496) suggest researchers need to have skills and capacities to "endure and work well through tough and messy situations not merely following fixed rules, calculations, and established norms" but using agility, intelligence, discernment, and strategy – what they call practical wisdom. Other authors stress the significance of collective leadership, defined as "groups of individuals from multiple organisations and sectors who lead transformational social change together through critical reflection, inclusivity, and care" as a way forward to foster transformations, including co-creation of knowledge (Care *et al.* 2021, p. 703). Below, we offer some ideas about facilitation and leadership in the context of research co-creation.

The involvement of skilled facilitators and the use of consensus-building tools can help identify key issues and guide the process towards shared goals that inspire broad participation. Facilitation ranges from vertical (person-centred by managers) to horizontal (team-centred by individuals in a team; see Müller *et al.* 2018), depending on the cultural, social, and economic context. Although vertically structured leadership may initially seem inappropriate for effective CCWK, two distinct exceptional approaches stand out – servant and dynamic – representing a paradigm shift in person-centred leadership.

(1) **Servant leadership** is an effective approach for facilitating co-creation, often adopted by professional researchers (Box 3; Hsiao *et al.* 2015, Coetzer *et al.* 2017). A servant leader prioritizes serving others over seeking power or control, either individually or as part of a group. By coordinating and harmonizing ideas and suggestions from participants, servant leaders foster an environment conducive to collaboration and innovation (Coetzer *et al.* 2017).

(2) **Dynamic leadership** excels in adapting to changing circumstances, turning challenges into opportunities, and making decisive moves during difficult times. Such leaders embrace risk and foster a shared sense of purpose among team members. Rather than relying on traditional command-and-control hierarchies, dynamic leaders inspire and motivate teams through influence and collaboration, thereby promoting innovation and teamwork (Al Rahbi *et al.* 2017, OcampoMelgar *et al.* 2024).

Box 3. Case study - A stakeholder-driven co-development of an equitable water resources management plan in the Western Cape, South Africa

Western Cape is a drought-prone province in South Africa, exemplified by the 2015-2018 drought which led to the "day zero" water crisis in Cape (Savelli et al., 2023), helping identify key issues among water users, especially among farmers and the agricultural sector, where conflicts are exacerbated by weak institutional frameworks to govern water usage.

A co-creation team was brought together to negotiate the effective and equitable sharing of water resources to ensure the resilience of environmental and economic flows (Gwapedza *et al*. 2024). Researchers from Rhodes University, NGOs, and local government followed a servant leadership approach by helping to produce tools and evidence requested by local actors to fill gaps and facilitate evidence-based decision-making (Figure 4).

Tools such as agent-based and water-sharing models were co-developed under the principles of Companion Modelling (ComMod) to ensure local salience and acceptability (Gwapedza *et al*. 2024). Local actors determined elements of the Adaptive Planning Process (APP), the iterative participatory decision-making method that enables stakeholders to collaboratively explore complex systems, co-create solutions, and adapt over time based on learning and feedback. For example, they mapped complex interactions between stakeholders and environments as part of the Actor Resources Dynamics and Interactions (ARDI) element, helping to unify the group around a collectively-defined shared catchment vision. Researchers iteratively modified the tools based on feedback collected in workshops arranged around the busy schedules of the Koue Bokkeveld farmers.

After multiple iterations, the finished tools and evidence were showcased in a workshop series and availed to the local Water Users Association. Water-sharing model outputs were presented to local actors as a role-playing game, allowing them to test multiple climate and governance scenarios.

Figure 4. Co-creation team trialling a water use roleplaying game, the outputs of which were used in a water sharing model. Image credit: Institute for Water Research, Rhodes University, South Africa.

In contrast, *horizontal leadership* offers an alternative approach, particularly effective in "well-established" communities or those constituted by members who actively participate in the decision making process and have a high level of experience and knowledge to share among them. Here, team members engage in a dynamic, interactive process where they mutually influence one another to achieve shared objectives. Unlike vertical leadership, where a single leader delegates tasks, horizontal leadership encourages team members to assume responsibilities aligned with their expertise while receiving support from the group. This fosters a strong sense of collective responsibility and unity, often referred to as "weness." Imam and Zaheer (2021) describe this as a leader-created environment where team members feel a strong connection to each other as well as to the organization's mission and correspondingly volunteer their own core expertise and receive the support of their whole team. By emphasizing shared responsibility, it creates an environment where collaboration thrives, ultimately driving the success of co-creation efforts (Gan *et al*. 2024). A step further, a care-based leadership model, which focuses on well-being, horizontal engagement, and deconstructing hierarchies, combined with the network's open communication and frequent interactions, fosters a sense of shared purpose and collaboration. This approach has successfully improved watershed restoration via co-creation in the uMzimvubu Catchment Partnership (UCP) in South Africa's Eastern Cape (Snorek *et al*. 2022), for example.

3.2.3 *Key tools and techniques*

CCWK requires creating a space where individual perspectives are elicited, discussed, and transformed equally among contributors. This section highlights tools for creating such spaces. These tools are less focused on the individual knowledge generation process through disciplinary methods, experiences, and traditional or Indigenous learning, and are more oriented towards shaping how this knowledge is welcomed and exchanged.

Inquiries on the current state ("*What is?*") and potential futures ("*What should be?*") of the human–water system help to understand water problems and find actionable solutions (*"How do we get there?"*).

- **"*What is?*"**: One common approach is using system thinking, such as qualitative system mapping/analysis, to identify and illustrate the complexity of social and environmental systems (HangerKopp *et al.* 2024). Such tools can be used when it is necessary to analyse and discuss water reservoir management (Höllermann and Evers 2020) or in land and water management planning (Proswitz *et al.* 2021). For inclusivity, it is important to provide different entry points (i.e. ways for participants to get involved) for systems thinking (ter Horst *et al.* 2024). Besides the more formal system analysis methods (e.g. causal loop diagrams, concept mapping, for planning nature-based solutions for water management; Castro *et al.* 2023), even visual and haptic methods are useful in engaging and capturing insights from diverse participants – for example, the problem tree method for planning flood risk management (Almoradie *et al.* 2020, Höllermann and Riemann 2023), the photovoice method (Wang and Burris 1997, Fantini 2017, Bennett and Dearden 2013, Russo *et al.* 2021), or transect walks and mapping, in particular when dealing with large-scale water systems (McNall and FosterFishman 2007, Castelli *et al.* 2018, Näschen *et al.* 2019). Such methods can be designed to be used for individual research but can also be implemented for effective participatory research and co-creation.
  Mapping an individual's understanding of a system can also be a useful first step to elicit an individual's perspective. Subsequently, participants can search for similarities and differences in their understandings to allow for adjustment and enhancement in an iterative feedback cycle. This process is not about right or wrong; it helps to visualize differences in perspectives and can reveal diverse ways of reasoning (Höllermann and Evers 2019), thus cultivating openness. Following this exchange of perspectives, participants can agree more on topics and define new aspects to establish legitimacy before envisioning future perspectives.
- **"*What should be?*"**: Scenario analysis and model-based projections are tools used to illustrate the future. In a co-creation process, such valuable information can serve as grounds for further discussion. Co-creation can also be a tool to develop scenarios and model-based projections jointly; this would also contribute to addressing inclusivity and representation within the development of a hydrological model (ter Horst *et al.* 2024). However, to adhere to the principle of inclusivity, an entry point (e.g. approach or method) is needed where everybody can contribute to scenario building or visioning based on their knowledge. For example, the impact/uncertainty matrix used to create four possible scenarios (van der Heijden 2005, Kruse *et al.* 2024) is especially suitable for participants with academic education; whereas the use of narratives, through stories, or fine (e.g. paintings) or performing arts (e.g. theatre, video; HoTassone *et al.* 2023) can provide creative alternatives that cater to different ways of knowing and problem solving than the other methods. Van Loon *et al.* (2020) found that a creative approach supported exchange and raised awareness of the hydroclimatic challenge for a larger group, including policymakers. By using these techniques, personal knowledge is reflected in the scenarios, thus enacting the principle of openness. The following discourse can be based on (partial) agreement or consensus about "*what is*" and "*what should be*" creating legitimacy, e.g. about adaptation measures (Höllermann *et al.* 2024) or other formats such as establishing long-term monitoring networks. Participants can discuss and develop actions based on their common inputs, moving from the status quo to the desired future state, supported by methods like the world café (Höllermann and Riemann 2023) and debriefing (Crookall 2023).
- **"*How do we get there?*"**: Co-creation inherently involves bringing together different ways of knowing to increase mutual understanding, establish common grounds, and create novel water knowledge that could not be generated using a single epistemology. There are different ways to frame this plurality, such as network analysis and debriefing to enable inclusive participation and knowledge transfer and exchange (Laursen *et al.* 2024) or actor mapping to understand who is in each person's individual network and, most importantly, who is missing (ZigaAbortta and Kruse 2023). Debriefing after an interaction can transform the experience into actionable learning (Crookall 2023) by asking, "*What will you change?/What will you do differently in the future?*" (Höllermann and Riemann 2023). Besides this, some co-creation approaches can be brought to the proper definition and design of tools and/or processes, employing more structured methodologies such as participatory design (Spinuzzi 2005, Castelli *et al.* 2018), or participatory modelling frameworks (Basco Carrera et al, 2017).

These tools and techniques highlight entry points to create inclusive and open spaces for CCWK, where individual perspectives can be elicited, exchanged, and commonly transformed. However, many others are available[2] and can be developed, and it is important to choose methods that resonate with the specific but various participants' ways of knowing.

3.2.4 Knowledge inclusion

The success of a CCWK process depends upon including new and revealed knowledge within a system, group, or action (e.g. policy or practice). Although, in co-creation, knowledge inclusion should be considered since the early stages of the project (Brandsen and Honingh 2018; Section 2.2), a reflexive process is still necessary to assess how the generated knowledge will be evaluated, how outputs, outcomes, and impacts will be delivered, and how forwardlooking reflections and recommendations will be formulated early in the process will increase their effectiveness. Such an iterative phase of knowledge inclusion is

[2]See the td-net toolbox https://naturalsciences.ch/co-producing-knowledge-explained/methods/td-net_toolbox

Box 4. Case study - "Grow with the Flow": co-development of an integral monitoring and forecasting platform for the Netherlands

This project aimed to develop an integrated monitoring and forecasting platform for water availability and use and crop growth in the Dutch agricultural sector. The tool is designed to support more efficient water use by farmers, enable insurance companies and water authorities to better manage floods and droughts, and adapt to climate change (Figure 5).

The co-creation team included universities, government agencies, and private sector partners, all with a direct stake in regional water availability and use. The project was motivated by widespread recognition that already available tools lacked robustness and integration between partners. For example, farmers used irrigation tools and water authorities used water balance tools, but they were disconnected. Furthermore, atmosphere-soil-water-crop interactions were previously neglected.

The new tool, presented as a mobile and web application, integrated water availability and use components, including short- to long-term weather forecasts. Central to this functionality was the development of a feedback mechanism that allowed users to input data and insights (e.g., on water availability and crop growth), which were continuously integrated into the modelling framework.

Early phases of co-creation with systematic mapping helped identify the key actors and their specific needs and perspectives. After this phase, specific meetings and online debriefing sessions served to gather input from actors and integrate their feedback in the co-development of the platform. The project used an agile approach based on scrum sessions (a management technique where large projects are split into smaller tasks that can be completed in short timeframes – it is increasingly common in environmental management) and incremental software development to maintain a regular cadence of interaction and co-design with the affected actors (von Unruh *et al.* 2022).

The four-year project was organised in phases. At the end of each phase, the tool was evaluated by the co-creation team and other potential users, and the feedback was incorporated into the subsequent phase. This iterative approach allowed continuous testing and refinement of the tool, ensuring their salience, acceptability, and usability.

Despite being in the testing phase at the conclusion of the project, all parties involved considered it a promising feature. For further development to be successful, additional efforts are needed to (1) operationalize and scale up the system, (2) secure long-term financial support, and (3) conduct a comprehensive needs assessment of the various actors.

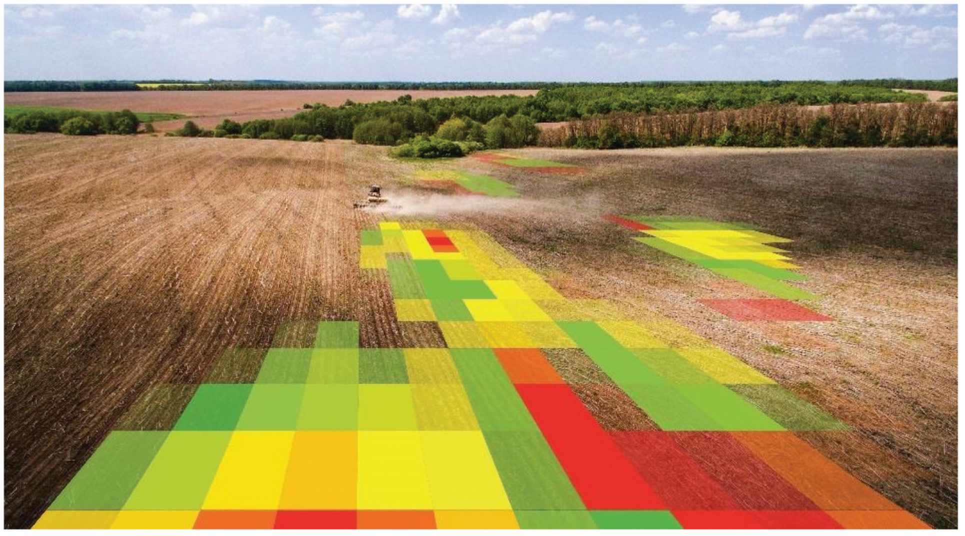

Figure 5. An example of how information in the water availability forecasting platform might be presented to users. Image credit: Bos-Burgering (2022).

one of the key steps of CCWK, and within the framework of this perspective, it is considered a standalone element that is transversal to the co-creation process and not a simple tool (Section 3.2.3).

Knowledge inclusion enables intercycle readjustment of the co-creation process, such as reformulating research questions and addressing emerging problems and new societal concerns. At the same time, it is also a key part of production (Section 2.2, Lang *et al.* 2012, Norström *et al.* 2020, Baur *et al.* 2010). It should include a thorough evaluation of the success of the CCWK processes and their outputs, outcomes, and impacts (Fazey *et al.* 2014, SchuckZöller *et al.* 2017). This component is among the most challenging (Mitchell *et al.* 2015) because no universal evaluation method exists, and success can have different meanings for different actors involved in the co-creation process.

The question of *who* is evaluating *who* and whose voice is heard is not trivial, as an increase in the number and diversity of participants may reduce the ability of any individual or group (especially those who are marginalized) to contribute powerfully to the CCWK process and its evaluation (Baur *et al.* 2010). Unconventional, less formal tools, such as narrative indicators, written reflections and blogs, and video narratives, may be more effective and synergetic than traditional participant interviews and key performance indicator monitoring (Norström *et al.* 2020).

Formative assessment, or a continuous evaluation process, may produce more mutual learning (Baur *et al.* 2010, Lang *et al.* 2012, Norström *et al.* 2020). Social change is more likely to be achieved through reflexive dialogue, for example, embedded in the CCWK.

At the same time, translating knowledge into action is essential for the CCWK to make a real-world impact, and the

Box 5: Case study - Water quality citizen science to promote environmental justice in an Indigenous community in Lake Titicaca, Bolivia

Mining, urban, and solid waste pollution in the Katari River Basin severely impact the water quality of Lake Titicaca, Bolivia's most critical water resource (Agramont et. al. 2022). Subcentral Chojasivi Indigenous communities are especially impacted because they rely on ecosystem services degraded by poor water quality.

In this project, 20 citizen scientists from the Subcentral Chojasivi Indigenous communities, primarily recruited at high schools, collected monthly water quality data and also interviewed community members at multiple sites within the basin over four months. The data were co-analyzed and interpreted in a series of workshops, contextualizing the results within the Bolivian environmental legal framework and Indigenous peoples' rights (Figure 6).

The analysis and interpretation revealed substantial water pollution, which explained and confirmed community reports of health issues (e.g., diarrhoea and skin rashes) and a decline in ecosystem services (e.g., food provision and cultural benefits), highlighting profound environmental injustices for participants and their communities.

The increased understanding of water quality issues and environmental injustices, backed up by the robust and locally relevant evidence base, stimulated increased community involvement in advocacy initiatives. Young people emerged as pivotal change agents, demonstrating a strong commitment to safeguarding their water resources. The findings highlight the potential for co-creation to empower marginalized Indigenous communities and drive environmental justice advocacy.

Figure 6. Chojasivi Indigenous communities learning how to use water quality testing equipment. Image credits: Afnan Agramont.

extent to which this is realized is a key measure of success (Zanetta 2025). The outputs must be of a nature (e.g. content, media, accessibility) that enables diverse actors to use and action them; different output formats are often required for different actors (Howard *et al.* 2024). Outcomes should be clearly defined, encompassing nonmaterial, unintended, and hard-to-measure consequences, such as relationships, social networks, and individual participant learning. Although these are not conventionally considered outputs for researchers, they hold significant value to participants and might be essential building blocks for long-term change (Norström *et al.* 2020). For publication outputs, attention should be paid to properly acknowledging the contributions of nonacademic cocreators via shared authorship, which may require rethinking credit attribution frameworks such as CRediT (Allen *et al.* 2019, Ifejika Speranza 2024) or other more relevant recognition of their contributions.

Successful co-creation requires consensus on how knowledge and solutions will be implemented, considering the multiple motivations of various players. A recent commentary (Mochizuki and Wada 2023) introduces "reflexivity" (Salmon *et al.* 2017) as a process that takes this knowledge inclusion step even further, emphasizing the importance of including broad sociopolitical perspectives to understand and implement effective co-creation. Mochizuki and Wada (2023) describe the tension between meeting end user demands and scientific advancement, emphasizing research novelty, and define the reflexivity step as the moment when – beyond disciplines and singular goals – beliefs and norms are questioned and broader understanding is incorporated. This last point reinforces a research goal that LotzSisitka and Burt (2006) describe as expanding progress indicators, i.e. to account for hidden dimensions, structural factors, power, and agency, adopting transdisciplinary approaches (De Angeli *et al.* 2025).

Regardless of the form of the outputs and the evaluation, returning new knowledge to the knowledge body and informing the continuation of the process is crucial for sustaining long-term knowledge co-creation and co-production, i.e. closing the knowledge loop (HagemeierKlose *et al.* 2014, Zanetta *et al.* 2025). This final phase is analogous to the reorganization stage of the adaptive cycle described in a panarchy framework, wherein the learning will have repercussions in multiple, complex social–ecological systems interacting across scales that must be acknowledged to be effective (Sundstrom *et al.* 2023). This added value, on a wider scale, legitimizes and justifies the additional time and resources required for CCWK (Lang *et al.* 2012, SchuckZöller *et al.* 2017). This step is the most important so that the co-creation cycle evolves, and water management practices improve and adapt.

4 Challenges and opportunities for the future

By the end of the HELPING decade (2032), we aim to develop a set of guidelines for CCWK. These guidelines will outline a process for interweaving different ways of knowing without establishing a hierarchy between them and recognizing their values and rich contributions to address present and future water-related challenges, while also fostering just and sustainable futures. Achieving this requires going beyond the analysis of shared principles and approaches presented here by addressing open challenges in the theory and practice of co-creation. In this section, we outline some of the most pressing challenges that currently hinder the wider application of CCWK approaches and make recommendations about how we, as a collective, can begin to address them.

4.1 Funding and structuring projects

Effective co-creation in water management and hydrological sciences necessitates the systemic restructuring of project structures and funding mechanisms. This involves integrating diverse knowledge across all stages of a project, requiring the active involvement of multiple actors from the outset (e.g. conception and proposal stages). Members of co-creation teams contribute scientific, local, and experiential knowledge, necessitating an iterative process that refines methods and outcomes based on ongoing feedback and evolving needs (Szałkiewicz *et al*. 2020, Maclean *et al*. 2022, Pajot *et al*. 2024). In this sense, decentralized and multiple funding and structural modalities, where nonacademic partners share planning and finance responsibilities, are a possible effective alternative to a single funding source. These frameworks enable a broader inclusion of perspectives and a more equitable sharing of power, enhancing the adaptability and inclusiveness of water management strategies (Pajot *et al*. 2024, Rusca *et al*. 2024). Such an approach ensures projects are more responsive to community needs and environmental challenges, leading to sustainable and effective water management solutions. One powerful example is the Tuscany Regional Law on participation (Pacetti *et al*. 2020), which allows communities and municipalities to request funding just for organizing participatory processes that could even be used to contrast or dispute other institutional policies or decisions.

4.2 Addressing power dynamics

Power dynamics can significantly hinder the effectiveness and equity of co-creation by suppressing marginalized voices and prioritizing dominant perspectives (Cleaver 1999, Thaler and LevinKeitel 2016, Reed *et al*. 2018, Nobrega *et al*. 2023, Rusca *et al*. 2024, De Angeli *et al*. 2025). Ensuring that different perspectives and forms of knowledge are not only discussed but also valued is crucial (Bréthaut *et al*. 2019). Power asymmetries, often ingrained in local cultures and institutional frameworks, may allow dominant groups to impose their views, limiting meaningful contributions from others. Power-sensitive research (Dewulf *et al*. 2019) is essential to ensure that the voices of marginalized groups are heard and respected, aiming to improve the lives of the most vulnerable communities (Botchway 2001, Carroll *et al*. 2020). Special designs, such as bilateral meetings or specific rules for interaction, may be required in contexts with extreme power differentials to ensure that less powerful groups' perspectives are considered. Although these measures might not entirely resolve power imbalances, ignoring them altogether could compromise the co-creation process and miss opportunities to deepen the understanding of these dynamics (Miller and Wyborn 2020, Scolobig and Gallagher 2021). Ethical considerations in co-creation, particularly ensuring equitable participation and addressing power imbalances, are crucial. Transparent communication and inclusive strategies protect all contributors' interests and enhance the effectiveness and equity of the co-creation process across different contexts (Walker *et al*. 2021, Maclean *et al*. 2022). In this sense, relying on multiple funding sources (section 4.1) could further balance power disparities among actors and between a single funder and the beneficiaries.

4.3 Operationalizing co-creation of water knowledge

While applicable to a much larger set of tools and practices, integrating co-creation within large-scale modelling and empirical experiments has the potential to provide innovative and effective solutions and to mainstream co-creation within hydrological sciences. This approach could enhance the accuracy and applicability of models and ensure empirical research is deeply informed by the nuanced needs of diverse social actors, increasing the relevance of research outputs (PahlWostl *et al*. 2011, McGinnis and Ostrom 2014, RubioMartin *et al*. 2021).

For example, the potential of citizen science to enhance hydrological studies has been widely recognized (e.g. Nardi *et al*. 2022). Centralizing citizen engagement in data collection and knowledge co-creation can help address data limitations, engage local participants and partners, and empower communities to make and demand change (e.g. Box 5; Buytaert *et al*. 2014, Nardi *et al*. 2022). Co-creation thrives when driven by end users' needs and desires, often making outcomes more technically feasible and practically relevant. Demand-driven co-creation fosters trust amongst partners and optimizes the use of resources (e.g. time, money, and effort) by focusing on essential features and functionalities. This method encourages an iterative feedback loop, enabling end users to continuously refine the co-creation process and improve solutions (Malm *et al*. 2020, Antonini 2021).

4.4 Institutionalizing co-creation

Institutionalizing co-creation in water management requires integrating these practices into the core operational frameworks and policies of public authorities (e.g. governments), universities, and nongovernmental organizations (NGOs). This means not only advocating for co-creation in individual projects but also embedding it within academic curricula and practices, and standard procedures and guidelines that govern water research and management activities. By formalizing co-creation as a cornerstone of decision making, policymaking, and management, organizations can ensure that it becomes a persistent, sustainable, and effective approach and signal the legitimacy of co-creation approaches amongst its members and partners. Institutional support, investment in human resources, continuous training, and economic resource allocation are key to making co-creation a sustainable and impactful practice. This shift will help mitigate challenges such as power imbalances, participation fatigue, and the erosion of local knowledge by making co-creation a routine and familiar aspect of decision making processes.

4.5 Overcoming epistemic injustice

Despite a growing body of research on co-creation, water knowledge remains dominated by top-down, Western scientific traditions, shaped by functionalist approaches and a strong preference for quantification, and in many contexts still determined by (post)colonial hierarchies. This dominance – often referred to as epistemic hegemony or prejudice – marginalizes individual and community knowledge (Venot *et al.* 2022, Rusca *et al.* 2024) and leads to cognitive (Santos 2015) or epistemic injustice (Kidd *et al.* 2017). Even in spaces and opportunities created for co-creation, groups that face epistemic injustice can be regarded as ignorant (e.g. of scientific or research project management norms) and not trusted to contribute or lead (Melandis and Hagerman 2022). Their contributions are often treated with suspicion, ignored, or regarded as below those of social actors who belong to the hegemonic knowledge tradition. This stands as a pervasive barrier to effective and equitable co-creation, and while a resultant exercise may be labelled as co-creation, outcomes lack diversity of knowledge and are only a reflection of the contributions of epistemic gatekeepers.

Epistemic justice in co-creation ensures that all forms of knowledge, regardless of origin, are recognized and valued equally. Overcoming epistemic injustice directly addresses several challenges within co-creation efforts by: (1) mitigating power imbalances by giving equal weight to every participant's knowledge, (2) overcoming tokenistic engagement by genuinely integrating diverse perspectives, (3) harmonizing diverse social contexts through the equitable inclusion of varied knowledge systems, (4) reducing participation fatigue by making engagement more meaningful, and (5) preventing the erosion of local knowledge by validating it and integrating it into broader research themes. Importantly, not only epistemic but also procedural, corrective, distributional, transitional, and recognitional justice have to be taken into account to cocreate water knowledge (Zimm *et al.* 2024).

Prioritizing justice considerations enriches the co-creation process, becoming a strong foundation for institutionalizing co-creation while also ensuring that it leads to more equitable, robust, and sustainable outcomes.

5 Concluding remarks

Addressing the pressing global water challenges requires transformative approaches to knowledge generation and application, and CCWK offers a critical pathway forward. In this perspective paper, we have conceptualized co-creation as an approach to knowledge generation, laid out the relevant principles and practices, and highlighted case studies to make co-creation approaches actionable. By identifying key tools, techniques, and challenges, and emphasizing the importance of justice, we provide a foundation for inclusive and equitable co-creation that values diverse knowledge systems, so as not to perpetuate inequalities CCWK is meant to address.

We urge the hydrological and water resources management community to adopt these insights and expand their efforts into co-creation where possible and relevant. We call on our colleagues to prioritize justice so that we, as users, managers, and researchers of water can collaboratively shape more equitable and sustainable water solutions. As we progress through the HELPING decade, this paper serves as a step towards refining and promoting co-creation practices and envisioning a future where diverse knowledge inclusion is a standard practice. Finally, the findings of this paper, despite being based on our experience in the water sector, can be useful for a comparison with other domains of the broader spectrum of environmental sciences.

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